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The purpose of this contract is to develop and demonstrate modern technologies and management practices that optimize the performance of the Department of Defense's Clothing and Textile's supply chain. Specific objectives are (1) eliminate recruit training center clothing stockouts; (2) minimize operational and inventory investment costs across the entire supply chain, and (3) level production requirements placed on manufacturers. Clemson Apparel Research participates in the C&T supply chain as a model quick-response shirt manufacturer supporting Army and Marine Corps RTC.

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1. Executive Summary

Background. The purpose of Clemson Apparel Research's Demonstration Contract is to develop and demonstrate modern technologies and management practices that optimize the performance of the Department of Defense's Clothing and Textile (C&T) supply chain. Specific objectives are to (1) eliminate recruit training center (RTC) clothing stockouts, (2) minimize operational and inventory investment costs across the entire supply chain, and (3) level production requirements placed on manufacturers. Clemson Apparel Research (CAR) participates in the C&T supply chain as a model quick-response shirt manufacturer supporting Army and Marine Corps RTCs. CAR also develops and implements integrated improvements for wholesale and retail operations.

Demonstration approach. This paper presents a summary of the work conducted during contract years 4 and 5. An earlier paper covered the first three contract years. Year 4 began with CAR manufacturing Army women's shirts for FLW on an emergency basis for the Christmas exodus and routinely manufacturing Marine Corps men's dress shirts for Parris Island and San Diego. All were produced on the BalancedFlow supply chain system that was developed during Years 1 through 3. During years 4 and 5 CAR continued to refine the BalancedFlow system. In addition, CAR provided assistance in maintaining the BalancedFlow principles in new software the ARN partnership was developing to support the transfer of ownership of retail assets to DSCP.

CAR also continued to manufacture and refine the supporting electronic order form (EOF) and pattern alteration software systems for its special measurement shirts. By the end of Year 5 CAR was on contract to make all special measurement requirements for all 28 military dress shirts.

At Parris Island CAR refined its BalancedFlow retail ordering software that was installed at the end of Year 3. These refinements improved the look and efficiency of the original software and added the capabilities for managing critical shortages and setting stockage objectives.

CAR's detailed participation in manufacturing, distribution, and retail replenishment for these items continued to produce many learning experiences that were used to improve the BalancedFlow concept while waiting for the ARN to implement BIFRS scheduling at the contractors.

2. Introduction and Background

Background: Reference is made to the earlier Clemson Apparel Research Contract Demonstration Final Report for Years 1 through 3 which documents all

research and lessons learned from the beginning of the demonstration contract until this reporting period. The findings and recommendations presented there were validated during Years 4 and 5 and are not repeated in this report. However, they remain valid and should be included in any comprehensive review of this overall effort.

Purpose: The purpose of Clemson Apparel Research's (CAR's) Demonstration contract is to support the Apparel Research Network's (ARN's) goal of creating customer driven uniform manufacturing (CDUM). Specific CDUM objectives are:

(1) Eliminating recruit training centers' (RTCs') clothing stockouts.

(2) Minimizing operational and inventory investment costs across the entire supply chain. This includes reducing inventories by at least 50 percent.

(3) Leveling manufacturing requirements.

Approach: CAR supports the ARN through research, through a manufacturing demonstration, and through a supply chain demonstration with one Recruit training center (RTC). CAR conducts independent research, maintains active membership in research committees of trade associations, and conducts research with other ARN partners. CAR demonstrates the results of this research plus other cutting-edge technologies and management practices by operating a fully functional model factory that produces commercial and military shirts. Supply chain research results are demonstrated at CAR, at Parris Island, at FLW, and with other ARN partners.

CAR's research in the first two years contributed greatly to the evolution of the ARN's efforts in ordering and inventory management. The ARN began its approach with a relatively balanced effort with focus groups in development and design, pre-production and production, and ordering and distribution. In Year 2, the ARN realized that the greatest opportunities for meeting the ARN objectives were in strategic inventory management rather than manufacturing or design. The overall ARN focus shifted to logistics through the formation of a virtual prime vendor (VPV) effort structured to make the most of these opportunities. Working closely with the Program Manager, DSCP, and other ARN partners, the CAR demonstration identified these opportunities, provided the essential concepts, and helped define the generic steps required to implement VPV during years 2 and 3.

During years 4 and 5 The ARN effort shifted to installing software at RTCs to support the transfer of inventory ownership from the Services to DSCP. CAR's efforts shifted to refinement of the supply chain principles and the complete development of what is now named the BalancedFlow concept. The BalancedFlow concept is documented in detail in a separate document entitled Balanced

Inventory Flow Replenishment System (BIFRS). Part I presents the theory, concepts and principles in detail to explain how they work. Part II provides step-by-step implementation instructions. Key principles, lessons learned, and operations of BalancedFlow are presented in this document.

CAR's initial CDUM research and demonstration efforts resulted in three major thrust areas within the CAR demonstration which are still valid today:

1. Manufacturing. The demonstration began with the focus on the manufacturing line and that continues to be one of our three major areas of emphasis, but it remains third in overall priority. The original purpose of the manufacturing demonstration was to locate, integrate, demonstrate, and transfer to commercial manufacturers the most modern manufacturing technologies and management practices. The primary benefit of the manufacturing demonstration has turned out to be all the lessons learned by CAR as a true manufacturer with all the problems and challenges faced by DSCP's contractors. These lessons have enabled CAR to keep the ARN research focused on the objectives that ultimately result in the most benefit to the overall program. The manufacturing line is the most scarce and expensive resource within the supply chain. The supply chain's natural constraint (bottleneck that would cost the most to purchase one step up in supply chain capacity) should reside within manufacturing. For a military apparel supply chain, many non-manufacturing bottlenecks are larger, but the DSCP contracting changes and the ARN research have eliminated or developed the means of eliminating most of these for recruit clothing. Everything possible external to the manufacturing line must be done to minimize manufacturing delays and costs. Everything possible within manufacturing must be done to minimize total manufacturing costs. This is a very different approach to manufacturing than first envisioned by the ARN partners! This is why manufacturing cost reduction is no longer the primary focus of the ARN.

2. Special Measurement Supply Chain. Shortly after the demonstration began, the Defense Supply Center, Philadelphia (DSCP) requested CAR manufacture special measurement (SM) shirts because of their large backorders and their inability to interest commercial manufacturers. These SM shirts became the primary focus of our production line for most of the first year and the associated pre-production work evolved into several very successful independent research efforts that now constitute our middle priority thrust area. We were forced to build efficient automated modules to manage orders, manipulate patterns, and ship garments within required time frames. Our research revealed unacceptable error rates as well as unacceptable delivery times with the existing SM ordering system. The Web-based electronic order form was created to overcome these ordering problems through a separate, but closely associated contract that is fully documented in a report entitled "Clemson Demo Electronic Order Form Final Report." The first three years of

the pattern manipulation work is documented in detail in a separate report entitled "Clemson Demo Special Measurement Final Report." We continue to improve the electronic order form and the automated pattern software. Early in Year 3 we implemented the ARN's primary automated production software from Georgia Tech and we have continued to modify it during Years 4 and 5 to minimize our pre-production times and costs. However, it is clear that it must be rewritten completely to be viable for commercial application for military or commercial items. At the end of Year 5 CAR was awarded a separate DSCP contract to manufacture all 28 special measurement dress shirts.

3. Virtual Prime Vendor. The highest priority thrust area is the SC replenishment concept named BalancedFlow with the supporting constraints-based scheduling software named Balanced Flow Inventory Replenishment System or BIFRS. BalancedFlow is a supply chain-wide management concept with supporting BIFRS software and systems that re-balances the flow of orders up the supply chain and product back down the chain on a frequent basis. It is being implemented in conjunction with other ARN projects as part of the overall VPV effort.

This report addresses each of the Tasks assigned to CAR during Years 4 and 5 with emphasis on the refinement of the VPV balanced flow concept. It begins in January 1999 where the first report for years 1-3 stopped. Emphasis is on the lessons learned that have enabled us to refine and complete the BalancedFlow concept.

3. Tasks

This section presents each of the original task definitions from the year 4-5 proposal and discusses how they were modified and accomplished during the report period.

3.1 Parris Island Inventory Reduction

***Task:* Assist Parris Island with draw down plans and monitor and report progress to ensure the retail goal of less than $4,000,000 is achieved by October 1999.**

PI began the year in January 1999 with $8.5 million in stock that would have been 139 DOS if all inventories were balanced. (The initial inventory was over $10 million and stockouts were over 4 percent when BIFRS was introduced and operated at Clemson early in 1998). Early in March, PI decided to modify the goal to be at $3.6M annual average stockage by 31 Aug 99. $3.6M equated to 60 DOS of balanced stocks and $2.7M equated to 45 DOS of balanced stocks. PI adjusted all targets downward to meet this goal including balancing only 7 DOS (rounded up to full case quantities) on the issue lines. Clemson's BIFRS-R software was

then used to control automatically the replenishment of the remainder of the retail inventory through visibility into MUMMS inventories of the quantity on-hand in bulk storage.

PI experienced major computer network problems through June and into July that prevented meaningful automated operations. They reverted to manual ordering of large quantities to prepare for the summer recruit surge. However, they were down to $3.9M by the end of July at the height of the summer surge. They hit a low of $3.65M at the end of August, but intentionally increased to $3.9M at the end of September in an effort to spend all available money before it was lost at the end of the year.

Most of PI's shipments were from Albany Depot and replenishment lead times were improving significantly. PI realized stockage objectives had to be reset in DSS because of these reduced replenishment lead times. This reduced replenishment lead-time plus the receipt of end-of-year buys pushed the inventory back up to $4.2M by the end of October. In addition, PI had to receive and post $1M in "free issue" boots in January, which again further increased inventories.

In February of 2000 Parris Island's depot support was changed from Albany to the new Vendor Park Southeast. By April of 2000 inventories were still at $4.4M, and Vendor Park Southeast's response times were improving significantly. However, PI decided to retain the longer times within BIFRS-R through at least half of the summer surge to eliminate any possibilities of stockouts. At the end of July inventories hit a high of $5.7M because of the peak in dress clothing receipts and the long order-ship-times still in BIFRS-R. In August, OSTs were finally adjusted down and inventories were down to $3.15M by the end of Year 5 in November of 2000.

Summary: Parris Island used CAR's BIFRS-R software during Years 4 and 5 to carefully reduce inventories from $8.5 million to $3.2 million. There were no significant stockouts during this time and no recruits departed with any uniform shortages in contrast to the original 4 percent stockout rates. CAR continued to monitor and report Parris Island's inventory levels into Year 6 to support additional inventory reductions.

3.2. Install BIFRS-R at Parris Island

***Task:* Install BIFRS-R at Parris Island. Separate BIFRS-W and BIFRS-R software, create user-friendly screens for retail item managers, install BIFRS-R at Parris Island, and complete user training by 2/1/99. Improve the software and resolve problems through Year 5.**

CARS separated BIFRS into retail BIFRS-R and wholesale BIFRS-W software programs late in 1998. CAR installed BIFRS-R at Parris Island successfully in December of 1998. BIFRS-R was designed to be a simple, easy solution to the supply chain's core problem of large, infrequent orders being generated at retail. It simply replaced the ordering module of MUMMS and obtained the desired results immediately. Replacing EOQ ordering modules is extremely simple, is not disruptive, and gives the wholesale system the flow of demand data required to exceed all ARN objectives. It is very clear this should be the first option for improving all other supply chains.

A new version of BIFRS-R was installed in May of 1999. This software was designed to assist the item managers in viewing and taking corrective action on critical shortages in the most efficient manner possible. Everything they needed to take action including wholesale order status was provided on a single screen. However, the essential lesson learned here is that the retail level managers at best can only identify critical shortages. Wholesale item managers must be given responsibility for identifying and fixing critical shortages because only they have access to all the tools. This was supported by DSCP taking ownership of retail assets, but there was insufficient interest on DSCP's part to institute a systematic approach to identifying and fixing critical retail shortages.

Summary: This task was completed successfully in May of 1999.

3.3. Develop Decision Support for Parris Island

Task: Implement Decision Support for Parris Island. Determine the forecasted consumption rate, the minimum required inventory buffer, and the optimum BIFRS-R ordering frequency.

The CAR Decision Support Software (DSS) was developed and installed at Parris Island as part of BIFRS-R in May of 1999. This provided item managers with automated assistance in setting issue line and bulk storage objectives in days-of-supply as driven from recruit accession projections.

Based on lessons learned from May through November of 1999, CAR simplified the DSS software and added additional features in January of 2000 that made it easier to run and more accurate.

Summary: Tasks 3.2 and 3.3 combined gave retail Item Managers a complete set of automated tools (1) to set stockage objectives based on their recruit forecast and replenishment wait times; (2) to generate a weekly flow of requisitions, and (3) to monitor problem replenishment orders on an exceptional basis. These tasks were completed in January of 2000 and their success validated through the end of Year 5.

3.4 Implement BIFRS-W for Marine Corps

Task: Complete automation of input and testing of the MC men's long sleeve shirt by Feb 99 (provided all data is available from the DataMart), provide a copy of BIFRS-W to PDIT for implementing and testing by Feb 99, and implement approximately one additional item per month until all items are on BIFRS-W. This implementation includes activating DAMWeb for each manufacturer and working closely with each item manager at DSCP as each item is activated. Milestones beyond 1 Feb 99 are dependent on the DataMart providing all required data for full electronic implementation. Testing of the first item through January will be conducted with direct entry of data that is not available through the DataMart. Inventory draw down will be the key focus for each item activated.

CAR completed development and testing of BIFRS-W late in 1998 and provided a copy to PDIT as scheduled.

In February of 1999 a most noteworthy ARN milestone was reached when, for the first time ever, total asset visibility was accomplished in near real time on an automated basis. Both Rutter Rex and CAR input WIP and FG inventories through DAMWeb on day one for the Marine Corps Men's long sleeve shirt. PDIT presented this data plus the other required data from SAMMS early on day two and CAR ran BIFRS-W to compute the new manufacturing requirements.

However, the implementation of BIFRS-W for manufacturers was delayed further beyond the end of Year 5 because of the ARN decision to implement QLM-Central to support centralized ownership of RTC inventories by DSCP. This placed PDIT's implementation of BIFRS-W low in priority and no further work was accomplished on this task by PDIT during Years 4 and 5.

CAR continued to develop, test, and refine the BalancedFlow and BIFRS-W concepts throughout the end of Years 4 and 5.

Summary: CAR provided BIFRS-W on schedule to PDIT, but was unable to continue the development of PDIT's web-based version of BIFRS-W because all resources were focused on the higher priority implementation of QLM-Central. This task was continued into Year 6.

3.5 Decision Support for Wholesale Item Managers

Task: CAR will complete the testing of its decision support model at the wholesale level for the long sleeve shirt by February 1999 with manually entered data. The model will suggest the seasonal inventory objectives,

the annualized day of supply, minimum inventory objective at wholesale, and the optimum BIFRS-W ordering frequency at the NSN level. It will also forecast procurement requirements in support of the strategic and tactical planning processes. The model bases its recommendations on historical demand data, the creation of balanced flow ordering, batch handling costs, and statistical analysis of issue/demand variations. This work will be accomplished using data manually extracted from the SAMMS Data Warehouse if it is not available from the DataMart. Upon approval by DSCP, CAR and PDIT will jointly propose an effort to automate data management and extend the model to all items. PDIT will have the lead in all data management and user interface portions of this effort.

Research was completed and CAR's BIFRS-W concept was expanded to include calculations for the seasonal inventory objective (SIO), the annualized day of supply (1ADOS), the retail or RTC day of supply (1RDOS), and the optimum BIFRS-W ordering frequency (BIFRS-W Cycle). These calculations will be included in VIM-BIFRS in Year 6. However, it became apparent as explained later in Section 3.8 that the wholesale minimum inventory objective is set by policy much higher than necessary and no effort was required to develop a model to compute it.

The final deliverable of providing a model to forecast procurement requirements was CAR's lowest priority task as assigned by the ARN and no CAR resources were assigned to this work. Once an item is on BIFRS-W, the recurring annual requirement becomes readily apparent and no model is needed. New items will require a forecast, but there appears to be no way to model this because of a lack of historical data. New items should be fielded on BIFRS with a minimum initial operational inventory, a seasonal inventory, and a liberal initial production capacity. BIFRS should be run weekly at first to ensure the correct size mix is produced. As accurate demand is obtained, the total demand and size tariff will stabilize as the pipeline is filled with the correct size mix. This portion of the task is unnecessary and considered complete.

Summary: Calculations were developed to compute the seasonal inventory objective (SIO), the annualized day of supply (1ADOS), the RTC day of supply (1RDOS) and the optimum BIFRS-W ordering frequency. These will be inserted into VIM-BIFRS in Year 6. A minimum wholesale inventory objective is not required because of the high wholesale stockage policy level of 120 to 135 days of supply. No resources were assigned to develop a procurement requirement model for new items because it became clear that this can be handled more appropriately by an fielding strategy based on a conservative forecast and BIFRS.

3.6 Transfer BIFRS-W to DSCP

Task: BIFRS-W will be installed at DSCP following the installation of AAVS at DSCP on a schedule to be determined by DSCP. This installation will include the BIFRS-W software engine that recommends new production requirements as well as management reports, Decision Support, and contract strategy. Training manuals will be used as well as on-site training of item managers. It is anticipated this will occur in Year 5 or beyond. CAR will manage all items active on BIFRS-W until the transfer occurs.

Summary: Since the implementation of BIFRS-W was placed on hold by the ARN, CAR could not complete this task.

3.7 Continue VPV QR manufacturing of MC shirts at CAR

Task: CAR will continue to manufacture approximately one hundred MC long sleeve men's shirts per week to demonstrate the ARN concepts. In addition, this task will be expanded to demonstrate how minimum system-wide costs can be achieved by fully integrating all aspects of pattern design, logistics, and alteration management. Manufacturing emphasis will be on modifying patterns to maximize automated manufacturing while minimizing alteration costs. A study of existing pattern dimensions and alterations will be conducted to see if standard pattern dimensions could be modified to fit more recruits adequately with fewer sizes. Finally, a cost study will be conducted to develop a model to minimize total costs considering all of the above parameters plus the optimum level for a special measurement policy. Deliverables are the manufacturing demonstration, manufacturing cost/time documentation, the pattern/alteration study, and a model for use on other items.

CAR continued to make approximately 100 selective sizes of MC men's long sleeve shirts per week to improve BIFRS-W through March of 1999. This resulted in the continued refinement of the BalancedFlow system and BIFRS-W for support of multiple retail customers.

However, no work could be accomplished with the Marine Corps on the pattern design portion of this task because the Marine Corps shirts were soon changed to Army shirts. In March the decision was made to terminate the Marine Corps shirts and make shirts for FLW instead to begin the research for manufacturing in support of the new QLM-Central initiative.

Summary: This task was terminated by the ARN in March of 1999 when CAR's ARN production capacity was refocused on QR shirts for FLW as explained in Task 3.8. This was in support of the major new ARN initiative to transfer ownership of FLWs' RTC inventory to DSCP.

3.8 Upgrade Army QR shirt manufacturing for Ft. Jackson

Task: CAR will continue to demonstrate and develop the balanced flow system to the Army by manufacturing approximately one hundred shirts for Ft. Jackson each week. Current plans are for the CIIP to install the software and hardware to transmit inventory data electronically early in Year 4. CAR will work with Ft. Jackson to fully automate this process in order to replace the current requirement for faxing the data weekly. Tasks include process design, automation and transmission of inventory data to CAR, testing automation software, integration of data into ARN-AIMS, and testing the complete system. The completion of testing is dependent on the availability of the new ACIIPS-R software and access to it. A plan will then be developed and presented to the Army to extend the VPV/BIFRS process to a limited number of other items and a commercial manufacturer.

Background: The Army uses a BIFRS replenishment concept that is different from the Marine Corps. The Army does not flow orders from their RTCs, but they are willing to permit CAR to maintain desired inventory levels by making partial shipments against large requisitions. Carrying partial due-ins for a long period of time causes some problems that must be resolved. We will continue this work to understand the new Army ACIIPS-R software and prepare for the implementation of the balanced flow concept on other items and/or at other Army locations.

At the end of Year 3 in November of 1998, CAR was manufacturing emergency orders of Army Women's shirts for Ft. Leonard Wood (FLW). Initially this was a temporary shift of CAR's ARN production capacity from the Ft. Jackson project to FLW because of commercial contracting delays. The purpose of CAR's focus on FLW was to demonstrate how BalancedFlow consisting of BIFRS-R, BIFRS-W, and fast-turn manufacturing could use a very small amount of production capacity and real-time TAV to solve a huge potential stockout problem.

The BIFRS-R concept was implemented immediately without installing the BIFRS-R software for the sake of speed and simplicity. BIFRS-R software was replaced by having FLW fax a copy of their on-hand inventory to CAR once a week. In addition, they submitted large orders for each size of the shirt and CAR was permitted to make and ship partial shipments against these "blanket" orders.

CAR ran a desktop version of BIFRS-W and successfully supported the Christmas exodus through December of 1998 with 200 shirts per week. This clearly demonstrated the power of total asset visibility combined with BIFRS-R, BIFRS-W, and fast-turn manufacturing to create a high-velocity balanced flow of orders and production.

Early in Year 4 CAR requested DSCP place CAR on bill and hold status for the FLW shirts it was making so CAR could develop solutions to problems contractors were encountering with DAMES and invoice payments.

Also, early in Year 4 FLW opened the possibility of transferring ownership of their inventories to DSCP. While investigating this possibility, the ARN decided CAR should make all sizes of the Army Women's short sleeve shirts for FLW. There were two reasons for this decision. First FLW's average annual weekly demand of 150 shirts almost exactly matched CAR's ARN production capacity and CAR-FLW would be a complete, closed supply chain. Second, this would permit CAR's research to support the new ARN initiative of DSCP taking over ownership of the inventories at FLW. CAR's tasks of manufacturing shirts for Ft. Jackson and the Marine Corps were terminated and changed to one task of CAR making all the short sleeve shirts for the women recruits at FLW.

Once DSCP assumed ownership of the FLW inventories, CAR used the SAMMS Data Warehouse to determine inventories on-hand at FLW and eliminated the weekly fax report from FLW.

Beginning in March of 2000 QLM-Central began recommending DVD shipments from CAR to FLW and SAMMS converted the recommendations to automatic Delivery Orders. In April of 2000 CAR discovered inconsistencies between the QLM-Central data and SAMMS data. Advantech then commenced to email weekly inventory reports to CAR to drive BIFRS. These inventory problems were resolved later in 2000 and CAR returned to extracting inventory data from the SAMMS Data Warehouse.

CAR was finally placed on bill and hold in June of 2000. However, DAMES was not capable of posting CAR's on-hand inventories and it required over four months for this to be corrected by Columbus. While this was happening, DSCP reverted to QLM-Central to support FLW from other sources. When CAR was removed as the single direct source for FLW, QLM-Central shipped so many shirts that no more were needed from CAR before the end of Year 5. QLM-Central was using a reorder point replenishment concept.

In August of 2000 CAR recommended to DSCP that CAR be placed on a commercial contract to make small quantities of all military dress shirts rather than just one shirt at a time under the ARN contract. The purpose was to eliminate critical backorder shortages at the same price DSCP was paying to their commercial contractors while fully developing BIFRS to handle multiple items. DSCP did not approve the recommendation because they did not expect to be in a critical backorder situation for dress shirts in the future.

In September of 2000 CAR was asked to assist DSCP once again with critical dress shirt backorders. This time it was the Air Force Men's long sleeve shirts. CAR made these instead of the Army shirts through the end of Year 5 and eliminated the critical backorder situation.

While CAR was making the Air Force shirts on a temporary basis, QLM-Central again pushed enough short sleeve shirts into FLW in November of 2000 to last well into the summer surge of 2001.

Summary: CAR began Year 4 by making shirts for the Marine Corps and for the Army. The manufacturing tasks were changed early in Year 4 into a single task so CAR could make all the women's short sleeve shirts for FLW in support of the new QLM-Central initiative.

Before this change was made, CAR was asked to support the Christmas exodus at FLW with its limited manufacturing capacity and the BalancedFlow concept. The outstanding results clearly demonstrated the advantages of the BalancedFlow concept over traditional contracting, manufacturing, and distribution. In addition, twice during Years 4 and 5, support of FLW was turned over to QLM-Central and the "reorder point" concept resulted in a flood of inventory into FLW. (And QLM-Central's ROP algorithm is much closer to a flow algorithm than standard ROP algorithms). This clearly established the superiority of a balanced flow replenishment concept over the traditional economic order point concept.

Once fully on DAMES, CAR began to learn firsthand all the problems contractors were encountering with this very unfriendly system. As a result, CAR developed a Task for Year 6 that would first automate and eventually eliminate the need for DAMES and EDI as well.

Late in Year 5 CAR suggested making emergency needs of all military dress shirts under manual BIFRS, but DSCP did not think they would need this kind of support in the future. CAR ended Year 5 making emergency Air Force shirts instead of the planned Army shirts for FLW.

This task was successfully completed in Year 5 and it led to many direct ARN benefits and a number of tasks for Year 6.

3.9 Manufacture all special measurement shirts for DSCP

Task: CAR will manufacture all special measurement shirts for DSCP. This project will complete the integration and development of all ARN efforts to improve the manufacturing of SM garments while providing a needed service to DSCP that commodity contractors do not want to provide. This budget request covers the initial set-up for each shirt. A separate contract direct with DSCP will cover the cost of each SM shirt produced. Implementation will be at the direction of DSCP. Shirts will be manufactured and delivered in less than two weeks. RTC orders will be delivered in one week. A copy of the proposal that was submitted to DSCP on 10 November 98 is attached.

Summary: DSCP awarded a separate contract for all 28 military special measurement dress shirts to CAR at the end of August, 2000. The contract required the activation of the individual shirts between the last week in November and the end of January. CAR had most of the patterns and tables ready to receive orders by the end of Year 5 and completed this ARN task in February of 2001.

3.10 Produce all special measurement markers for DSCP

Task: ARN-funded resources are budgeted to commence this work later in Year 4 and continue into Year 5 after the SM shirt development work is well underway. This project is an outgrowth of, and will be conducted identically to, the SM shirt project. The ARN funding will be used for initial development work and DSCP funding will be used to cover the costs of each marker produced. Advantages of fully implementing this project include faster delivery of garments, elimination of production and contracting processes at DSCP, and lower total costs for production markers. In addition, unlike the marker making office of DSCP, CAR has all apparel CAD systems currently used by Government contractors. Tasks include evaluating the SM marker process at DSCP including the historical demand and types of alterations per item, determining CAD capabilities of current SM garment manufacturers, proposing an implementation plan, and phasing the items in at CAR. A copy of the proposal that was submitted to DSCP on 10 November 98 is attached.

Summary: DSCP did not award the SM contract in time to begin this follow-on research before the end of Year 5.

3.11 Reduce manufacturing indirect labor costs charged to DLA

Task: CAR has been very successful in expanding production of commercial items in order to lessen the overhead funding requirements from DLA. The 60 percent contribution goal is exceeded in the Year 4 budget and continues to decline in the Year 5 budget as shown in the following table:

Labor Category	Yr 3 Man-months	Yr 4 Man-Months	Yr 5 Man-months
Data Control Clerk	4	4.00	3.00
Asst Site Director	12	5.00	3.00
CAD Engineer	6	5.00	4.00
Eng Assoc II	12	7.00	6.00
Mfg Eng	12	6.00	3.00
Cutting Supervisor	6.5	5.00	3.00
% Charged to Demo Contract:	72.92	44.44	30.56

Table 1 – Year 3 Actual Charges and Budgets for Years 4 and 5

Actual Man-months used and charged to the Demonstration Contract are shown in the following table:

Labor Category	Yr. 3 Man-months	Yr. 4 Man-months	Yr. 5 Man-months
Data Control Clerk	4	8.43	7
Assistant Site Director	12	4.21	8
CAD Engineer	6	0	9
Engineer Associate II	12	13.53	13
Manufacturing Engineer	12	4.58	3
Cutting Supervisor	6.5	7.30	33
% Charged to Demo.	72.92	26.43	37.5

Table 2 – Year 3, 4, and 5 Actual Charges

Summary: CAR continues to cover more manufacturing overhead from commercial work and less from the ARN Demonstration contract. Only one-third of the overhead for Years 4 and 5 was covered by ARN funding which is down from more than two-thirds in Year 3.

3.12 DSS Support of Manufacturing

Task: CAR will continue to develop decision support to optimize production batch sizes, finished goods inventory buffers, and transportation batch sizes for the MC men's long sleeve shirt. In conjunction with PDIT, CAR will propose a task to extend this to other manufacturers on an automated basis. The purpose of this portion of the

DSS model is to optimize production and shipment batch sizes considering costs and benefits across the entire supply chain.

A basic law of commercial supply chain optimization is that buffers and transfer batch sizes must be reduced until all the downstream benefits do not outweigh the cost of increased batch changeovers on the manufacturing constraint.

In researching this area, it became clear that we do not want to minimize all manufacturing buffers and transfer batches for a military supply chain. Since the BalancedFlow system that the ARN is implementing does not have the objective of minimizing all inventories (for example, the 135 DOS policy for recruit bag items), this task became much less complex. Under BalancedFlow, all military SCs can operate easily within this inventory level.

The correct ARN objective should be restated as follows: ***Given the 135 wholesale day-of-supply stockage policy, how do we launch manufacturing and distribution to minimize total costs while maintaining a 100 percent service level?***

CAR developed simple optimization logic for launching manufacturing and included it in the items produced at CAR during this period. This resulted in the need to define by garment style (PGC) the optimum number of bundles per cut and the optimum number of fabric plys per cut. This gives us the optimum quantity per cut. The next step is to match the calendar days of annualized demand to the workdays for the manufacturer based on this optimum quantity per cut. This is then posted on the calendar and we must run BIFRS as scheduled for this optimum quantity to keep a steady flow of production at optimum cut levels. This procedure will be implemented in VIM-BIFRS.

CAR verified that QLM-Central has the capability to approach BalancedFlow for distribution decisions through its reorder-point software. In addition, DSCP's ownership of assets at retail will ensure the capability exists to flow consumer demand to wholesale. Now, we only have to take care that no one is permitted to return to the old system of batching orders.

Summary: The research portion of this task is complete. Implementation must be accomplished through VIM-BIFRS and QLM-Central. VIM-BIFRS must accommodate and honor the contractors' minimum sized cutting batch quantities at both the PGC and NSN levels. QLM-Central must select values for replenishment parameters that flows the shipments downstream without overloading the buffers at the RTCs. CAR will insure this is implemented properly.

3.13 Redirect resources to take advantage of new opportunities

Task: Resources will be redirected as required by the ARN Program Manager to take advantage of new opportunities that are developed as a part of the ARN process.

Summary: CAR obtained and installed one TC2 scanner and one Eastman scanner for evaluation. In addition, CAR conducted scanning of new cadets at West Point during the summer of 2000. The results of this work will support future scanning proposals.

4. Key Lessons Learned

As stated in the introduction, the highest priority thrust area of the Demonstration was the supply chain replenishment concept titled the BalancedFlow supply chain. This concept named the Balanced Inventory Flow Replenishment System (BIFRS) and its supporting software are covered in detail in Parts I and II of the Balanced Inventory Flow Replenishment System Report referenced above.
The BIFRS concept began to take form when CAR first produced shirts for Ft. Jackson. First, we conducted a study of our ability to forecast the arrival of orders so we could have the inventory available. We concluded we could not do this without a huge inventory because of the unpredictable nature of the orders. However, it was clear that the arrival of recruits was in fact very predictable.

At the same time we began to receive and fill real orders. While we had more than sufficient capacity over the long-run, we could not fill the first complete order before the second and third arrived. We found ourselves doing the same thing that is common across all manufacturing. We called the customer, determined the minimum quantity that was really needed immediately, expedited production orders to meet this need, and made partial shipment of the current needs.

This solved everyone's problems. We realized we needed to institute an automated system to do this in a routine manner. The resulting solution was to replace the legacy batch ordering replenishment module at retail with a software package that flowed the demand up the supply chain. At the same time, we had to reduce the size of our manufacturing batches to meet the short-term needs of retail with a minimum buffer of inventory. Thus was born the concept of flowing orders and production while balancing all items at the same level of supply.

Following is a summary of key lessons learned as we developed the balanced flow concepts in detail. They are extracted and presented here as a ready reference for all ARN researchers. The most important ones are presented in bold type.

4.1 Optimize commercial supply chains by making the right item fast

A BalancedFlow supply chain (SC) consists of two major parts. The first is the constraints-based SC scheduling software for replenishment (BIFRS) and the second is fast-turn manufacturing.

4.2 Expected improvements in stockouts, inventory investment and costs

A BalancedFlow commercial SC improves retail stockouts by 20 percent, eliminates 80 percent of total SC inventories, and reduces the cost of manufacturing by 10 to 20 percent over conventional SCs.

4.3 Objectives are different for military supply chains

A BalancedFlow military SC will result in the same level of benefits except that a policy level of inventory will be maintained to protect against contracting delays and surge requirements. Thus, military SCs are different from commercial SCs in that the objective of a military SC is to eliminate retail stockouts while positioning surge inventory to operate at the lowest possible cost during peacetime and wartime. Commercial SCs have the objective of eliminating retail stockouts while minimizing total inventories, product costs, and operational costs.

4.4 The ARN must address wartime surge

Inventory maintained in a military SC should be strategically placed to enable surge production while minimizing total taxpayer costs. This has not been addressed by the ARN.

4.5 The driving operational metric must be throughput speed

Throughput (defined as the rate at which money invested in raw materials is converted into new money through retail sales) is the most important operational metric for any SC.

4.6 The potential results of local actions must be evaluated across the SC

A SC can only be improved by introducing change through local SC segments. Local changes should be approved only when the cumulative impact on the SC's goal (as measured by the net impact on the goal through each of the four objectives) is positive.

4.7 Traditional replenishment processes are the source of the problem

Each operational segment of a conventional SC contains a process and a buffer. Many also contain a replenishment module for the buffer. This is the primary source of problems and improvement opportunity.

4.8 Radical improvements require the crossing of boundaries

Radical SC improvements require the crossing of functional or organizational boundaries so that the SC partners operate as one entity rather than at cross purposes driven by local optimization.

4.9 A 75 percent service level is the optimum for Conventional SCs

Conventional SCs do not approach 100 percent service levels because variations in customer demand and customer wait times are high. Stocking to approach 100 percent service levels requires an order of magnitude of inventory greater than that required for a 50 percent service level. Most retailers set a target of an 80 percent service level and struggle to exceed 75 percent.

4.10 A 100 percent service level is attainable with *less* inventory

BIFRS is based on a thorough understanding of SC science. This includes the performance of individual SC segments and the relationships between segments and the consumer. BIFRS is designed to take every possible action to minimize all variations while maximizing product sales, customer response times, and product quality. BIFRS enables a SC to approach 100 percent service levels with significantly reduced inventories and total costs.

4.11 BIFRS drives only the few *strategic* SC segments

BIFRS manages the entire SC through a very small number of SC segments. These segments are strategic segments because they contain established levels of inventory larger that the absolute minimum requirement. This inventory is used to accelerate items that are being consumed faster than forecasted while those that are being consumed slower are left in these SC segments.

4.12 BIFRS is constraints-based SC-wide scheduling software

BIFRS is the only known constraints-based scheduling software that schedules the entire SC for SC-wide optimization. A number of commercial software packages claim to be constraints-based manufacturing scheduling packages. However they are either not constraints-based or they require so much data input that they are not feasible in operation.

4.13 Consumer pull (1ADOS) drives the entire BF supply chain

SC time and inventory are connected on a one-to-one basis with the expected rate of consumer demand being the connection. This is defined as one annualized average day of supply (1ADOS) in BIFRS and it drives every strategic segment of the SC rather than conventional metrics such as machine speed and production lead-time. This 1ADOS is defined by the consumer as the expected rate of consumption. It connects and drives each SC segment.

4.14 A day removed from PLT results in two days of inventory reduction

Each day of inventory that the Fast-turn effort removes from work-in-process permits the removal of a second day of inventory further down the SC.

4.15 Constraint capacity must be equal to average annual demand

The entire SC must be run from its natural internal constraint that is somewhere in manufacturing. This natural constraint must be operating at the same average annual rate as the consumers are placing demand on the SC. Otherwise, either consumer demand will not be met or inventory carrying costs will be greater than necessary.

4.16 Gating operations must be tied to manufacturing constraints

If more work is introduced into the SC at the gating operation than the constraint can process, inventory builds up and the SC is extended in time. If less work is introduced into the SC at the gating operation than the constraint can process, the constraint becomes starved.

4.17 The manufacturing constraint determines SC performance

The manufacturer only has to focus on the constraint operation to manage the entire SC. Minimizing changeover time on the constraint gives the SC huge flexibility in increased capacity, lower inventories, or lower item costs.

4.18 Expediting results from the failure to honor the constraints

Expediting and all associated costs including backorders exist primarily because the SC's natural constraint has not been identified, localized, and managed. This includes all expediting - retail, wholesale, and manufacturing.

4.19 BIFRS trivializes the importance of forecast error

BIFRS trivializes the forecast error by checking frequently for deviations and taking automatic corrective action.

4.20 BIFRS uses 1RDOS to redistribute the SIO

BIFRS uses 1ADOS for wholesale and manufacturing requirements. Distribution must use the retail day of supply forecast for the week at the end of the customer wait period for replenishment stocks (1RDOS). This simply moves seasonal inventory to retail just in time for surge consumption and dampens the replenishment process on the back-side of the surge requirement. Keeping most of the SIO upstream of retail provides flexibility and coverage of unexpected RLT and demand variations.

4.21 Paired Production is a *mandatory* strategy

Paired production is the optimum strategy for highest service levels and lowest total manufacturing costs. The large batch production line should be set for minimum manufacturing costs. The small batch production line should be set for maximum speed. Small production batches taken off the large line plus quick response orders of all types feed the small batch production line. Both lines together meet consumer demand and the average cost is lower than running all requirements down a single large production line. Paired production is essential for minimizing inventories and maintaining retail confidence at the same time. The large batch production line will have a very few delivery failures. The small batch production line making exactly what is needed very quickly fills the voids. This creates confidence in the retailer who no longer has to carry a maximum of every item "just in case" of stockouts of a very few items.

4.22 Flowing retail orders provides the most improvement the fastest at the lowest cost

Creating a flow of orders from retail as close at possible to the flow of demand placed on the SC by consumers is the most important, least expensive, and fastest way to improve a SC.

BALANCED INVENTORY
FLOW REPLENISHMENT SYSTEM
(BIFRS)

Glossary

1ADOS	One average annualized calendar day of supply computed by dividing the forecasted annual demand by 365 days. Used to determine long term contracting and production requirements.
1RDOS	One average weekly retail calendar day of supply computed by dividing the forecasted weekly demand just beyond retail's replenishment wait time (RWT) by 7 days. Used to determine ordering or shipping requirements to maintain the retail buffer at a target level to support short-term forecasted demand requirements during the week immediately following the retailer's replenishment wait time.
B	Buffer. Inventory waiting for processing. Pairs of processes and their supporting buffers constitute supply chain segments.
Bd	Distribution buffers. Strategic distribution buffers support strategic distribution or shipping decision-making processes.
Bek	External constraint buffer. Strategic buffers that support the supply chain's strategic external constraint processes of consumer demand. Normally thought of as the buffer of retail inventory, but is the buffer next to any consumer.
BF	BalancedFlow. A supply chain that is first balanced in days of supply and then shortened in time through high-velocity order and product flow.
Bg	Gating buffers. Strategic gating buffers support strategic gating processes.
Bi	Non-strategic buffers that support non-strategic processes.
BIFRS	Balanced Inventory Flow Replenishment System. The supply chain scheduling software component of the BalancedFlow system.
Bik	Internal constraint buffers. Strategic internal constraint buffers support the supply chain's strategic internal constraints.
BIO	Basic Inventory Objective. The supply chain's inventory objective or target stockage requirement expressed in quantity or days of supply without consideration of inventory protection for promotional or seasonal demand variations.
Bs	Scheduling buffer. Strategic buffer of manufacturing orders or requirements that supports the strategic process of scheduling.

CAR	Clemson Apparel Research.
CWT	Customer wait time. The time the downstream process owner has to wait for order fulfillment once a replenishment order is passed upstream. More commonly called replenishment lead time or RLT.
DBR	Drum Buffer Rope. The Theory of Constraint's (TOC's) replenishment concept consisting of the customer's drumbeat of demand, a buffer of inventory that ensures immediate demand fulfillment and a rope connected to the upstream gating process. A signal is sent by the rope for new work in a manner that maintains the optimum buffer level based on real-time consumer demand.
DOS	Days of supply. The number of calendar days that a given quantity of inventory is expected to last while supporting a forecasted consumer demand.
FG	Finished Goods. Completed work-in-process (WIP) residing in a buffer at the manufacturing facility waiting distribution or shipping decisions.
INV	Inventory. A TOC parameter consisting of all the money invested in inventory that will be consumed once all the money invested in operating expenses (OE) is used to convert the inventory into throughput (T).
Lean	The Toyota concept of operating a production line or supply chain with minimum inventory.
Non-Strategic	Identifies the many non-strategic buffers, processes, and segments of the supply chain. These process owners should have no choices of what to work next. Their buffers should be reduced to minimum transfer batch quantities in order to minimize throughput time (TT) for the entire supply chain.
Octane	An analogy to the different octane ratings for gasoline that are a measurement of combustion temperature and power. Within a manufacturing plant Octane is the relative contribution to profit of each SKU based on the total operating expense (OE) of the plant and the SKU's contribution to throughput (T).
OE	Operating Expense. A TOC parameter consisting of all the money paid to convert money invested in inventory (INV) into throughput (T).
P	Process. Value-added physical transformation or movement of orders up or inventory down the supply chain. Pairs of processes and their supporting buffers constitute supply chain segments.
PBT	Production Backlog Time. The number of days the next customer order must wait in the scheduling buffer (Bs) before it can be released to manufacturing through scheduling (Ps).
Pd	Strategic process that determines distribution or shipping

	quantities and priorities.
Pek	Strategic external constraint process of consumer demand. Generates the primary drumbeat that should drive every upstream process in the supply chain beginning with Pik.
Pg	Strategic gating process that must to which new production orders must be released in a manner to maintain the target buffer level for the internal constraint (Pik).
PGC	Process Group Code. An identifier that is used to group families of individual items that have minimum changeover requirements on the constraint process (Pik).
Pi	Non-strategic processes.
Pik	Strategic internal constraint process (the largest bottleneck in relationship to the supply chain's goal) normally found within manufacturing. Should be the primary target of scheduling and should be operating at the same pace as Pek adjusted for seasonal or promotional demand and inventory residing between Pik and Pek.
PLT	Production Lead-time. The standard number of days required to produce an item once the order is released to manufacturing. Within BIFRS this does not include the variable amount of production backlog time (PBT) an order has to wait in the scheduling buffer to reach its turn for release to production because this wait time is eliminated. However, many manufacturers have highly variable PLTs because they release all orders to manufacturing and have no ability to control and monitor production backlogs separately from manufacturing lead-time. Total manufacturing lead-time = PBT + PLT.
Ps	Strategic scheduling process. This can refer to the legacy scheduling process or the B IFRS scheduling process.
RLT	Replenishment lead-time. The time the downstream process owner has to wait for order fulfillment once a replenishment order is passed upstream. Also called customer wait time or CWT.
SAHs	Standard allowed hours. The standard allowed time in hours for a process or task. Can refer to the time required for a single SKU on the task or process or a batch of SKUs on the task or process. Item costing, production operator pay, and production scheduling are all based on these standard times.
SAMs	Standard allowed minutes. The standard allowed time in minutes for a process or task. Can refer to the time required for a single SKU on the task or process or a batch of SKUs on the task or process. Item costing, production operator pay, and production scheduling are all based on these standard times.
SC	Supply chain. Refers to a complete supply chain as defined by

	SKUs, processes, buffers, segments, sections, batches, and is uniquely defined by the one common internal constraint process (Pik).
SIO	Seasonal inventory objective. The days or quantity of inventory required by week when the demand is seasonal or promotional for the manufacturing line to operate at a level rate every week of the year. This is inventory required above the basic inventory objective (BIO) to avoid penetration of the BIO during the periods of high seasonal or promotional demand.
Six Sigma	The process improvement methodology used very effectively by General Electric and other manufacturers.
SKU	Stock keeping unit. Normally a retail number used to uniquely identify a basic item. Used by BIFRS across the entire supply chain to identify basic items within each supply chain section. The SKU for a single item may change from supply chain section to section.
Strategic	Identifies the limited supply chain processes, buffers, and segments that have sufficient intentional inventory to permit the process owners to have choices of different SKUs to process next. BIFRS determines the priority and quantity of work for each strategic process owner to rebalance the entire supply chain based on the inventory status of the supply chain from the position of each strategic process owner to the end of the defined supply chain.
T	Throughput. The primary TOC parameter consisting of the new money generated by converting inventory into sales by the application of operating expenses (OE). BalancedFlow uses TP rather than T.
TAV	Total asset visibility. The state of capturing inventory levels from all segments of the supply chain in a manner that permits high level visibility and informed replenishment decisions.
TB	Target buffer. Any strategic buffer of inventory located at the end of a supply chain section.
TIO	Total inventory objective. The total inventory target for the supply chain for a given week computed by summing the basic inventory objective (BIO) and the seasonal inventory objective (SIO) for the given week.
TM	Throughput money. A CAR BalancedFlow acronym used to break the TOC definition of throughput (T) into its two elements of throughput money and throughput time.
TOC	Theory of Constraints. Introduced by Goldratt in his book The Goal in 1986.
TP	Throughput. A BalancedFlow acronym used instead of the TOC acronym "T" for throughput.

TT	Throughput time. A BalancedFlow acronym used to break the TOC definition of throughput (T) into its two elements of throughput money and throughput time. TT is the primary metric and driving focus of the BalancedFlow system.
WIP	Work in process. Production orders released to the manufacturing floor by scheduling and not yet transferred to Finished Goods. Encompasses any number of supply chain processes and buffers.

BALANCED INVENTORY FLOW REPLENISHMENT SYSTEM (BIFRS)

Part I
Balanced Flow Concepts

Part II
Balanced Flow Implementation

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BALANCED INVENTORY FLOW REPLENISHMENT SYSTEM (BIFRS)

Part I
BalancedFlow Concepts

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Balanced Inventory Flow Replenishment System Concepts

1. BalancedFlow Concept Summary

CAR offers a unique supply chain (SC) order fulfillment methodology with constraints scheduling that multiplies SC partners' profitability. It is called the BalancedFlow (BF) system and the software is named the Balanced Inventory Flow Replenishment System (BIFRS). The BF system eliminates replenishment and production batching, balances inventories and accelerates the flow of replenishment stocks in shortest supply down the entire SC based directly on consumer-driven demand. SC balance is achieved when multiple items at different inventory levels and consumption rates are expected to meet consumer demand for the same amount of time. When balance is achieved, safety stocks are eliminated and the risks of stockouts and excess inventories are minimized and equalized for all of the individual items in the SC.

Once SC balance is sufficient to eliminate retail stockouts without significant safety stocks, inventory buffers across the SC are reduced to maximize SC throughput velocity. In turn, faster throughput results in even faster responsiveness to consumer demand, enabling increased capacity, additional inventory reductions, improved quality, and more accurate demand forecasts. **BF** ***SC throughput is defined as the rate at which raw materials are converted into new money through consumer sales*** in contrast to traditional local optimization measurements such as production lead-time, product cost, marginal contribution to profit, and efficiency.

BIFRS uses balanced inventories and high velocity throughput to optimize SC performance by minimizing stockouts, inventories, operational expenses, and manufacturing demand variations, ***all at the same time***. BIFRS first re-balances the entire SC as frequently as plant scheduling occurs by activating resources only for items that are in shortest supply down the entire SC. (If legacy scheduling can not be accelerated, BIFRS takes over the scheduling function.) Next, BIFRS re-balances each segment of the SC from strategic buffers forward to the end of the SC as frequently as on-hand inventories can be collected. Finally, BIFRS lowers inventories in all buffers and transfer batches to minimize inventory investment while responding faster to consumer demand. Stated differently, a BIFRS driven SC maximizes balance and throughput velocity by selectively processing raw materials, work-in-process, and finished items in distribution that will turn into cash the fastest.

In addition, BIFRS computes the true relative throughput contribution of each product through a measurement called OCTANE so demand generation managers can, for the first time, set proper priorities for all order generation actions such as marketing focus and sales commissions.

BIFRS is a cutting-edge Web-based system that is built upon SC science. It integrates concepts from all leading process methodologies with emphasis on Lean Enterprises, the

Theory of Constraints (TOC), Six-Sigma, and world-class teamwork. BIFRS is unique because it is an engine that runs the entire SC based on operating parameters established by the SC partners. As such, it generates radical improvements that go well beyond the promise of all other automation systems which only make the old methods of doing business and their supporting transactions more efficient and less expensive.

BIFRS is the first true constraints-based scheduling SC software and it multiplies the profitability of the SC partners because it extends scheduling from the initial manufacturing segments of the SC to the consumer. This optimizes the performance of the entire SC from the consumer through raw materials manufacturing thereby eliminating the common sub-optimization that exists currently in all SCs.

2. The BF SC Goal and Objectives

The goal of any commercial enterprise is to maximize profits - now and in the future. ***The goal of the BF commercial SC is to multiply profits – now and in the future – for each SC partner.*** The goal is attained through the four primary objectives that are:

(1) to minimize retail stock outs,

(2) to minimize INVENTORIES, and

(3) to level manufacturing requirements,

(4) while minimizing OPERATING EXPENSES.

Eliminating stockouts increases profits to the retail partner immediately through additional sales and to all partners in the future through repeat business. Minimizing inventories converts stock to cash immediately and reduces interest expenses in the future for each SC partner. Leveling manufacturing requirements increases manufacturing profitability immediately and results in additional sales in the future through lower item prices. Minimizing SC-wide operating expenses increases each partner's profitability immediately and in the future. Operating expenses (in the form of increased changeover costs on the manufacturing constraints) are also the limitation to infinite improvements in stock outs, inventory expenses, and manufacturing demand variations.

All efforts to attain the SC's goal through its four objectives can only be realized through actions or changes initiated at local segments of the SC. These objectives are so interrelated that ***any*** local action taken to attain one objective has high potential for SC-wide impact (positive or negative) through all four objectives. **Thus, local changes are undertaken only when the cumulative impact on the SC's goal (as measured through the net impact on the goal through each of the four objectives) is positive.**

3. The Defined Supply Chain

A SC consists of series of defined events and segments that generate orders and produce defined products as shown below. The SC begins at the most downstream point where consumption occurs. It extends upstream through retail operations, distribution, wholesale decision-making, manufacturing assembly, manufacturing of parts, and raw materials replenishment.

Branches can join the main SC at almost any place via a fish-bone type connection. For example, parts for assembly can come from many different SCs. There is a unique and special branch SC upstream of the buffer of unreleased orders. This SC branch consists of everyone who is generating demand (unreleased orders) for the SC. Throughput OCTANE should be the driving metric for everyone in this SC branch.

Demand can be for either standard or customized items. Standard items may or may not be stocked and customized items can not be stocked in finished state. Order fulfillment consists of (1) replenishing standard items that are launched in manufacturing to a forecast in anticipation of future orders or (2) reacting to unique custom orders. These SC characteristics apply to any or all portions of the SC. For example, a consumer may order a customized item that is made from standard components that the manufacturer carries in stock in anticipation of future demand.

The following figure shows the high level segments of a typical retail to manufacturing SC. It begins with the consumer who is at the tip of the arrow (there could be other high level segments such as distribution) and extends upstream to raw materials.

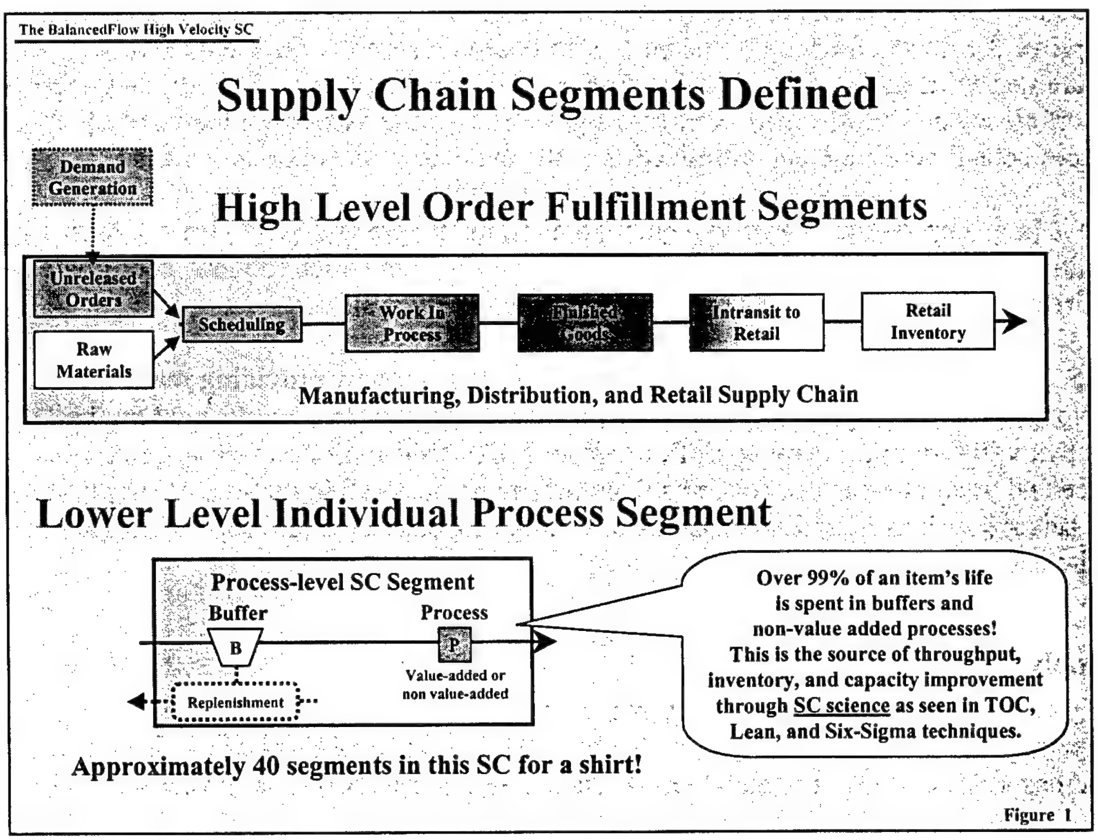

Figure 1

Figure 1 - Supply Chain Segments Defined

Figure 1 also shows the breakdown of the SC to individual process level segments that contain a process, buffer, and replenishment module. Each processes consists of one or more tasks, each normally taken immediately after the next by one individual before the work and responsibility are passed on to the next segment in the SC. Value added processes modify the physical form of the product or move it to the buffer behind the next process. Buffers reside directly behind each process and contain work that is waiting for the process. Replenishment modules exist in all SC segments that send a signal upstream that more incoming materials are required.

A typical end-item manufacturing through retail SC has 20 to 40 of these segments and it is important to recognize that all action taken on a SC has to be initiated through one or more of these individual segments.

The first problem encountered in a SC is that the replenishment modules accumulate demand and send it upstream infrequently in large batches. When this is multiplied many times up a SC, the upstream process owner feels like he is at the tip of a bullwhip that is held in the hand of the consumer.

In addition, manufacturing process owners batch production runs going back down the SC in the name of "efficiency," paying little attention to the inflated demands that are presented! It is normal for the performance of each segment owner and their supervisors to be measured by the performance (efficiency and budget) of these individual segments with no regard as to the real impact on the entire SC. Senior executives meanwhile strive to improve the financial health of the enterprise based on a totally different set of measurements that are not linked to day-to-day operational measurements. In fact, these local efficiency and budget measurements supported by their associated management practices actually ensure local optimization at the expense of the entire enterprise.

There is large opportunity for improvement both in orders going up and product going back down the SC if we can establish a higher platform from which to view, coordinate, and direct the SC activities. This higher platform is the BF system.

BIFRS transforms this sub-optimization into SC optimization by providing real-time directions to each strategic SC process segment owner so everyone works next on the items that will turn into the most profit the fastest. BIFRS is built upon supply chain science and integrates proven concepts from the major successful practices of supply chain science such as Lean Enterprises, the Theory of Constraints (TOC), Six-Sigma, and world-class teamwork.

4. Supply Chain Science Overview

Supply chain science is the body of knowledge that provides a comprehensive understanding of the statistical, financial, and operational relationships that exist within and across a SC. Once we are able to understand and express these relationships

mathematically, we can accurately predict and thus control the actions taken through the individual SC segments to achieve our established goal and objectives. The BF system is grounded in SC science, fully engages the minds and creative energy of everyone who manages the strategic segments of the SC, and multiplies profitability through the synergy of the entire SC in contrast to prevalent local optimization. The two leading application models for SC science are found in Lean Enterprises and the Theory of Constraints. However, these and all other prominent models were developed primarily for manufacturing lines while BIFRS extends BF scheduling to the entire SC. In addition, we emphasize the importance of the application of SC science through world-class teamwork to achieve optimum and sustainable results as quickly as possible at the lowest cost.

4.1 Lean Enterprises

The lean principles of consumer-defined value, value stream mapping, flowing the value stream based on consumer pull, eliminating waste, and immediate feedback have produced the world's most effective SCs as demonstrated in Japan and to a much lesser extent in the United States and Europe. Toyota created lean manufacturing following World War II in direct contrast to mass production. The complete transition to Lean Enterprises required over 20 years for Toyota even though all the prerequisites were born out of the end of the war.

The use of lean principles to convert mass production enterprises to Lean Enterprises has proven to be extremely difficult. The two major problems are a lack of focus within the lean manufacturing concept for the application of limited resources and the absence of true world-class teamwork and thinking in existing mass production enterprises. CAR's BF system integrates the Theory of Constraints and lean principles with world-class teamwork to provide the SC focus for enterprises that have an understanding of teamwork and lean or constraints manufacturing. This facilitates the implementation and optimization of both major parts of the BF system; the SC BIFRS scheduling and the production floor conversion to fast-turn manufacturing.

The BF concept uses common terms such as "lean," "modular," "quick response," or "agile" interchangeably to simply mean fast-turn manufacturing.

4.2. Theory of Constraints

The Theory of Constraints (TOC) is the premier methodology for defining a system's goal, determining its core problems, defining the system's constraints, eliminating policy constraints, and optimizing the system through its natural physical constraint in relation to its stated goal. TOC draws from SC science to define a system as a series of sequential and dependent events with statistical fluctuations in which every local decision has potential impact on the goal of the entire system – not just impact on the local SC segment.

A SC meets TOC's definition of a system because it consists of a series of sequential segments beginning with raw material manufacturing and extending to consumer sales and the outcome of each segment is dependent on the outcome of the previous segment. Attaining BalancedFlow begins with the SC partners' statements of their business goal

and supporting objectives. It then efficiently provides the partners very effective and focused tools with which to achieve their goal through their stated objectives and the driving focus of throughput velocity.

TOC also articulates very simply and clearly the integration of a company's operational goals and measurements with its financial goals and measurements. These measurements are based on SC science and straightforward common sense. Their application leads to proper management decisions in sharp contrast to the common use of cost accounting for operational decisions.

Three operational measurements define, explain, and are used to control the business operations. They are throughput, inventory, and operational expenses. Everything falls in one of these three measurements. TOC defines THROUGHPUT (TP) as the rate at which the system generates ***new*** money. INVENTORY (INV) is defined as all the money invested in things that are being converted into THROUGHPUT. INVENTORY is someone else's money that just passes through our system. OPERATIONAL EXPENSE (OE) is all the money we pay to convert the INVENTORY into THROUGHPUT. We will show these three terms in all capital letters from this point forward to indicate the specific meanings and relationships as defined here.

4.3 The Importance of World-class Teamwork to BalancedFlow

Supply chains are first and foremost about teamwork. World-class teamwork is defined as a group of people working together under pressure to realize a common goal in such a manner that their allegiances for one another are far superior than their allegiances to the organizational structure from which they came. A world-class team is on the opposite end of the continuum from a committee, achieves radical improvements rather than incremental improvements, and almost always requires professional help to grow and survive through the team-building steps. The BF concepts, especially the production floor portion, achieve the greatest results when they are implemented through world-class process owner teamwork.

5. THROUGHPUT Time (TT) – the SC's Driving Focus and Performance Metric

The BalanceFlow goal is attained through the four interdependent SC objectives that together optimize the relationship between revenue and costs across the entire SC. The driving operational focus and measurement of success in achieving these objectives is THROUGHPUT time (TT).

5.1 TT is the Critical SC Performance Measurement

THROUGHPUT (TP) is defined for a system as the ***rate*** at which the system generates ***new*** money through consumer sales:

THROUGHPUT = New Money/Time

New money equals the selling price minus all INV and totally variable costs that can be attributed directly to specific products. INV consists of raw materials and anything else such as packing materials that we purchase that goes into our products. Totally variable

costs consist of sales commissions, transportation costs, and etc. New money does not include anyone else's money that is just passing through our system, but it is money that is available to cover our OPERATING EXPENSES (OE) and, hopefully, our profit. OE is all of the money we pay to convert INV into TP or new money. Direct labor and all other costs that can not be linked to specific products are included in OE. The rate is the dollars per unit of time or speed at which money invested in all INV plus totally variable costs is converted into sales.

The two ways of increasing THROUGHPUT are to increase the numerator (new money) or decrease the denominator (time). Increasing prices, increasing units sold, or reducing the cost of INV increases new money. Speeding up the conversion of INV into sales decreases time (INV turns). Thus, speed is by far the greatest profit multiplier because it increases new money and decreases time. Speed increases new money through faster responsiveness to customers, which increases sales, and it decreases INV investment by removing INV from the SC. Actions taken to increase speed also reduce OE. Finally, speed or time is the direct mathematical link to labor that is also time based.

> ***The BF High Velocity System*** focuses on the time component of the above THROUGHPUT equation because time is by far the most powerful and important success driver in the quest for our goal of maximum revenue at minimum cost. The restated BF equation is defined as:

THROUGHPUT (TP) = THROUGHPUT Money (TM) / THROUGHPUT Time (TT)

TT is now our most important operational metric for the overall performance of the SC. It is the lowest common denominator for measuring the relative performance of each segment of the SC. In the form of responsiveness to consumer needs, speed or time has huge value to the customer.

The customer wants demand fulfillment at the fastest possible speed. Virtually every component of cost is based on time. Minimum TT addresses both the cost reduction and revenue generation sides of the business equation. Speed is by far the single greatest profit multiplier and is inadequately addressed by most companies today.

5.2 Types of TT across the Supply Chain

The four major TT components of a manufacturing-through-retail SC are retail, distribution, manufacturing, and raw material TT.

5.2.1 Retail TT

TT at retail is defined as the time from identifying that a replenishment item is needed until that replenishment item is ***sold*** to the consumer. This is a comprehensive definition that opens every opportunity for increased TT. The first segments of retail processing are recognizing the need for and ordering replenishment INV. These are variation-generation processes that should be ***eliminated*** by establishing target days of supply for the retail buffer and letting the manufacturer or distributor maintain the target levels automatically

through the established SC parameters. Driving the SC from the lower variation consumer demand (rather than from batched replenishment demand) is the first, easiest, and largest improvement step that should be taken in most SCs. This eliminates the operating expenses of ordering and permits a reduction in TT time and inventories equal to the time between order initiation at the retailer and the initiation of order fulfillment at the supplier.

The other segments of retail TT are receiving, stowing, stocking, and selling with their associated buffers. Every day or hour required for an item to move through these retail buffers and processes requires a corresponding day or hour of inventory further downstream. Collectively, the entire retail buffer is the most critical buffer of the SC because it provides the protection for the external constraint of consumer demand. Speed must be increased carefully here to avoid critical stockouts. This is the last place to improve TT by reducing inventories. In fact the retail buffer should be reduced only after the SC is in sufficient balance to protect the external constraint from stockouts. This buffer can be reduced to an absolute minimum only when retail processing times are minimized and consumer demand forecast error variations and replenishment cycle variations are brought within statistical control.

BF however approaches this absolute minimum by checking retail inventories as frequently as daily and initiating replenishment action automatically and frequently based on jointly established replenishment parameters.

5.2.2 Distribution TT

Completed items normally reside in a buffer before undergoing some type of transfer process between one SC partner and the next. This may be as simple as direct shipment from finished goods or as elaborate as a formal distribution system. The time requirement to make the distribution decisions and to move the inventory to the next SC partner defines the distribution or TT in this portion of the SC.

5.2.3 Manufacturing TT

Traditional manufacturing lead-time is a very large component of SC TT and it normally represents the most costly part of the entire SC. However, the manner in which it is commonly used limits SC profitability because of local optimization. BIFIRS deals with manufacturing lead-time in an unconventional manner. It does not make use of an overall manufacturing lead-time, but breaks manufacturing steps down into individual SC buffers and processes so local actions can be evaluated and managed based on their impact on the consumer-driven global SC through each of the four SC objectives.

TT for the entire SC is the sum of TT for each individual buffer and process. TT for individual processes depends on the number of items in the process batch plus the rate at which the process is running. This rate is normally defined as standard allowed hours (SAHs) or standard allowed minutes (SAMs) per operation. For example, the local TT standard for an individual process would be 30 minutes for batches of 60 items at a SAH of 30 seconds per item. If the batches were reduced to 30 items, the TT time for the local process and the SC would go down ***by half*** (less the changeover handling time of the

doubled batches) to 15 minutes. Thus, we can usually ignore the small amount of processing time (30 seconds per item) and safely state TT depends only on the size of the buffers and batches (30 minutes per item).

However, the local process capacity would go down slightly by the extra batch handling time and the direct labor cost would go up slightly by the extra batch handling time. This means that direct labor costs and SC capacities are connected to TT at the buffers and batches by the metric of time. Even more important, SC capacity and TT are ***only*** connected at the buffer and process batches of the internal constraint because capacity lost on non-constraint processes can be made up. ***Thus, the internal constraint's buffer is the one precise point at which all four of our SC objectives are interconnected.*** This is the reason constraints management is so critical for optimizing all 4 objectives at the same time.

The two TT-related measurements of capacity and direct labor costs offer great opportunity for multiplying SC profitability when properly addressed by constraints management across the entire SC. Capacity and labor costs are addressed in later sections.

5.2.4 Raw Materials TT

Extending the defined SC upstream to include the supplier segments and items optimizes raw materials TT and further ***multiplies*** profitability for all SC partners. Suppliers, just like end-item manufacturers, receive automated BIFRS production and shipping requirements based on total asset visibility all the way to the retail end of the SC. Once all items and raw materials for an end-item manufacturer are on BIFRS, legacy scheduling can be terminated to further reduce operating expenses. TT velocity and profitability increase significantly each time another segment is added to the SC and especially when organizational boundaries are breached.

5.3 Radical TT Improvements require the Crossing of SC Boundaries

TT velocity and profitability increase significantly each time another segment is added to the SC. In fact, the number of organizational boundaries that are encompassed by the defined SC determines the degree of improvement. A local process owner has a very limited sphere of ownership in which he can make changes and improvements. A first line supervisor has a larger sphere of ownership, but his power to make changes is still very limited. Incremental changes of 10 to 30 percent are normally possible within a plant under the sphere of ownership of the plant manager. ***When the SC includes the retailer on one end and the raw material suppliers on the other, radical improvements of 80 to 90 percent are normal.***

The driving focus of TT applies directly to all members of the enterprise engaged in the core business area of order fulfillment. There is a very special version of TT that is a TP multiplier and it applies directly to the core business area of demand generation. It should also be understood and used by those personnel in product development and customer service. BalancedFlow refers to this TP multiplier as THROUGHPUT OCTANE or just OCTANE.

6. OCTANE – the THROUGHPUT Multiplier for Demand Generation

Companies offer for sale hundreds to thousands of different products. Common sense tells us that some products must contribute more to the bottom line than others. How can we accurately determine the relative profit contribution that each makes so we can properly focus efforts such as new product development, marketing priorities, item pricing, sale force compensation, and even production priorities when we can not deliver all orders when requested? Clearly, we should set our product priorities in the manner that maximizes both short and long-term profitability. ***OCTANE gives us correct relative product profitability measurements where cost accounting commonly used for this purpose almost always leads to exactly the wrong operational decisions.***

6.1 How OCTANE Works for Product Costing

OCTANE is the measurement that easily permits the accurate discernment of each product's relative contribution to overall TP. OCTANE is TP at the product level based on new money generated by the product per unit of time required on the constraint. The equation for TP OCTANE for a particular SKU is:

SKU OCTANE = SKU TM / SKU SAHs on the constraint process

OCTANE, as a measurement of the contribution to OE and profit per time unit on the constraint, represents the relative profitability power within each product or SKU. Products are the fuels that drive the moneymaking engine of the enterprise. The higher the OCTANE, the greater the TP. Only when managers know the correct relative profitability of their products, can they take appropriate actions to maximize the demand for the most profitable ones and, if required, trade off the least profitable ones.

OCTANE, as a special case of TP, is computed in the same manner as TP. OCTANE is the new money generated by the SKU divided by the SAHs required for the SKU on the SC's internal constraint process. The constraint is the process in manufacturing that has the lowest capacity. The numerator is the SKU's selling price minus its INV and any additional totally variable non-OE selling expenses directly linked to the specific SKU.

Classical cost accounting does provide a metric of profit per product, but it is based on two assumptions that are almost always invalid. If used for this purpose, cost accounting measures of SKU-level profitability can result in many profit-diminishing decisions.

6.2 Why Cost Accounting does not Work for Product Costing

There are only two major sources of manufacturing costs; money invested in INV and money paid out as OE to convert INV into TP. Cost accounting was invented many years ago to support mass production when the "overhead" component of OE was only about 15 percent of OE. The other 85 percent was for direct labor. Overhead was relatively low and direct labor was readily available to support payrolls and it just happened to be the natural constraint. Thus it was both convenient and appropriate in the beginning to spread the unassignable overhead costs across the constraint of direct labor costs for each product. Cost accounting today still assigns overhead to a particular product by the

amount of direct labor cost required to make that product relative to the amount of direct labor required by all other products. So, is there a better way of assigning these overhead costs that can not be directly linked to individual products? There is if the way we assign overhead can help us realize our goal better than the way we currently assign it.

Two things have changed since cost accounting was invented when mass production originated in the early 1900s. First, it is not unusual today for overhead to be as high as 85 percent of an item's OE. The original OE contributed to the category of overhead has exploded over the years as both the number of products and the complexity of our SCs have expanded. Overhead costs are no longer trivial. If we do not assign them properly this can now have unintended, but devastating impact on our business when we make any management decisions concerning the relative importance of our products.

Second, direct labor is seldom the constraint today as it was from the early 1900s through the period following the end of World War II. We now know how to find the constraint, fix it in place and manage the flow of all products through the SC by the constraint. Does it not make sense to always give priority to the products that generate the highest profitability per unit of time on the constraint? This is exactly what cost accounting did (either intentionally or by accident) when it was first created. If we spread our total OE evenly across the available capacity of the constraint, we can generate a meaningful and useful measurement of new money generated or SKU-level THROUGHPUT.

The constraint can be thought of as the carburetor of the engine that generates power to propel our SC forward in the race to maximize total THROUGHPUT or profitability. The power generated depends on the OCTANE of the fuel that we put in the tank as well as the amount of fuel that the carburetor can deliver to the engine. We have many different choices of OCTANE to burn in our engine because we have many different products and each has a different OCTANE. ***To generate the most power possible, we should always run our engine on the highest-OCTANE fuel available.***

We have stated the imperative that every order fulfillment process owner must work next the order that will turn into cash the fastest. The companion imperative for every demand generation process owner is that they should maximize the sale of the highest-OCTANE products. When demand generation process owners honor OCTANE, the SC's strategic order fulfillment process owners can use BIFRS to ensure they always work next the order that optimizes THROUGHPUT for the entire enterprise.

The SC partnership that implements BalancedFlow constraints scheduling, OCTANE, and fast-turn manufacturing through world-class teamwork wins!

7. Buffer Science (How the SC Building Blocks Work)

Upon initial consideration, it appears our first objective of minimizing stockouts at the end of the defined SC directly contradicts our second objective of minimizing all SC inventories! It seems obvious the solution to stockouts is simply to stock more. Is this not what we have all been doing forever? ***Then why do SCs not work – retailers usually are***

in stock between 70 and 80 percent of the time for the items they intend to have in stock. Everyone "knows" it is too costly to achieve that last 10 to 20 percent of stock availability. Lets see if we can visualize, define, and understand what is really happening within a SC.

We stated earlier that all action on a SC must be introduced through single segments of the SC. Segments consist of buffers, processes, and replenishment modules. When we flow or "value stream map" a SC and determine the amount of time orders or production batches reside in individual buffers and processes, we always see that well less than 1 percent of an item's life is spent on value-added operations. The other 99 plus percent of the time the items are just sitting around accruing interest and carrying costs while increasing the risk of obsolescent. Almost all of this non-value added time is spent in buffers. Only a small portion is spent on processes that are not really value-added. This means we should definitely develop first a complete understanding of buffer science in order to optimize buffer operations.

7.1 The Buffered Relationship of Supply and Demand

Since buffers sit between supply and demand, lets start here. The following figure shows the generic buffered relationship between supply and demand:

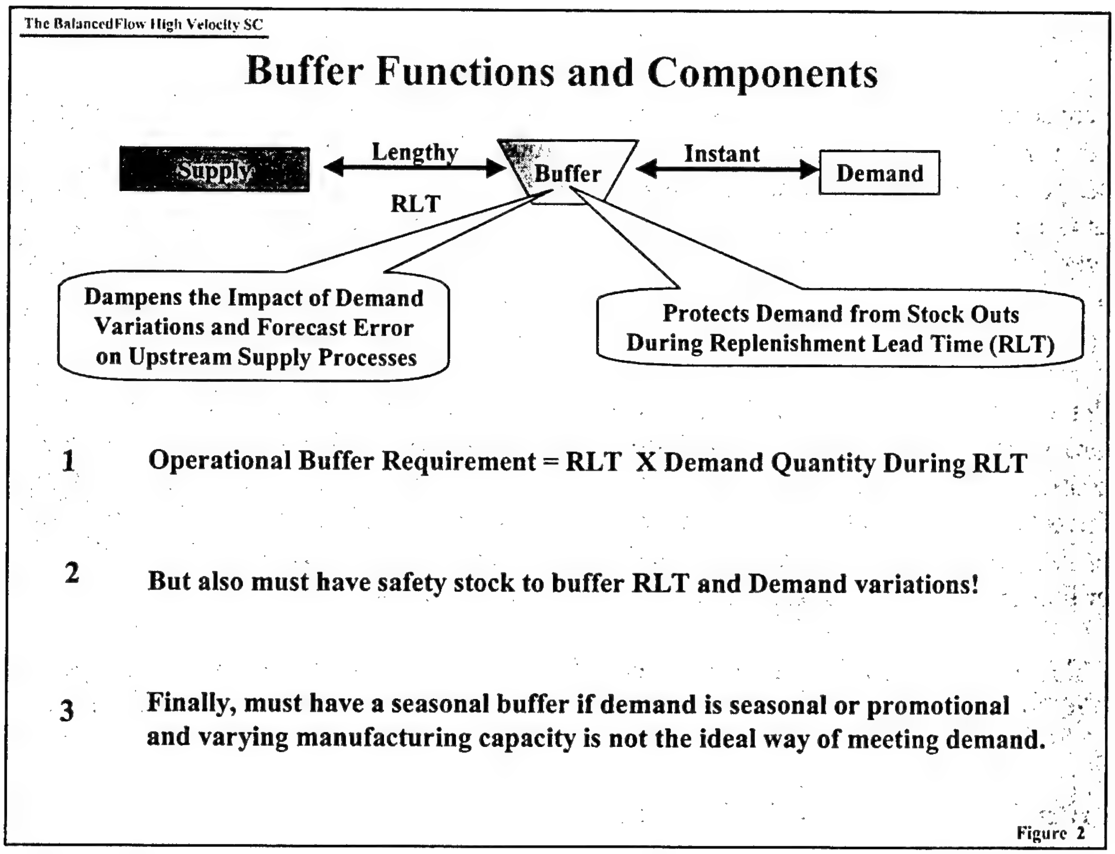

Figure 2 – Buffer Functions and Components

The concepts presented here apply to any buffer anywhere in the SC, but lets begin by thinking of the strategic buffer of retail stock as we build our understanding. Thus, the demand shown on the right is the demand placed on the SC by consumers. The buffer exists to protect the consumers from stockouts when the consumer places demand on the SC. The size of the buffer depends primarily on the desired service level and the replenishment lead-time (RLT) or the time it takes to replenish it from the next buffer up the SC (if we could have unrestricted and instantaneous replenishment, we would need no buffer). The buffer size also depends on the amount of expected demand during each unit of RLT. The buffer also exists to protect the SC from having to react immediately to demand variations and forecast errors (if we could eliminate forecast error, we could eliminate a lot of our buffer stock). The amount of inventory required in the buffer depends on the desired safety level, the average RLT, average demand quantities per time period, and the respective variations of the RLT and demand quantities.

We can break a buffer down into its 3 basic components as shown above and address each one individually. First, the basic or operational buffer requirement is the average RLT times the average demand per unit of lead-time. Second, we must decide how much of the potential RLT and demand variations we want to protect against through safety stocks. Finally, we can split out the third component of seasonal or promotional demand and deal with it separately from operational and safety requirements.

7.2 The Statistical Basis behind Buffer Replenishment

The following figure takes us into the statistical relationships that explain the interactions between RLT and demand as we attempt to minimize both stockouts and buffer stockage levels.

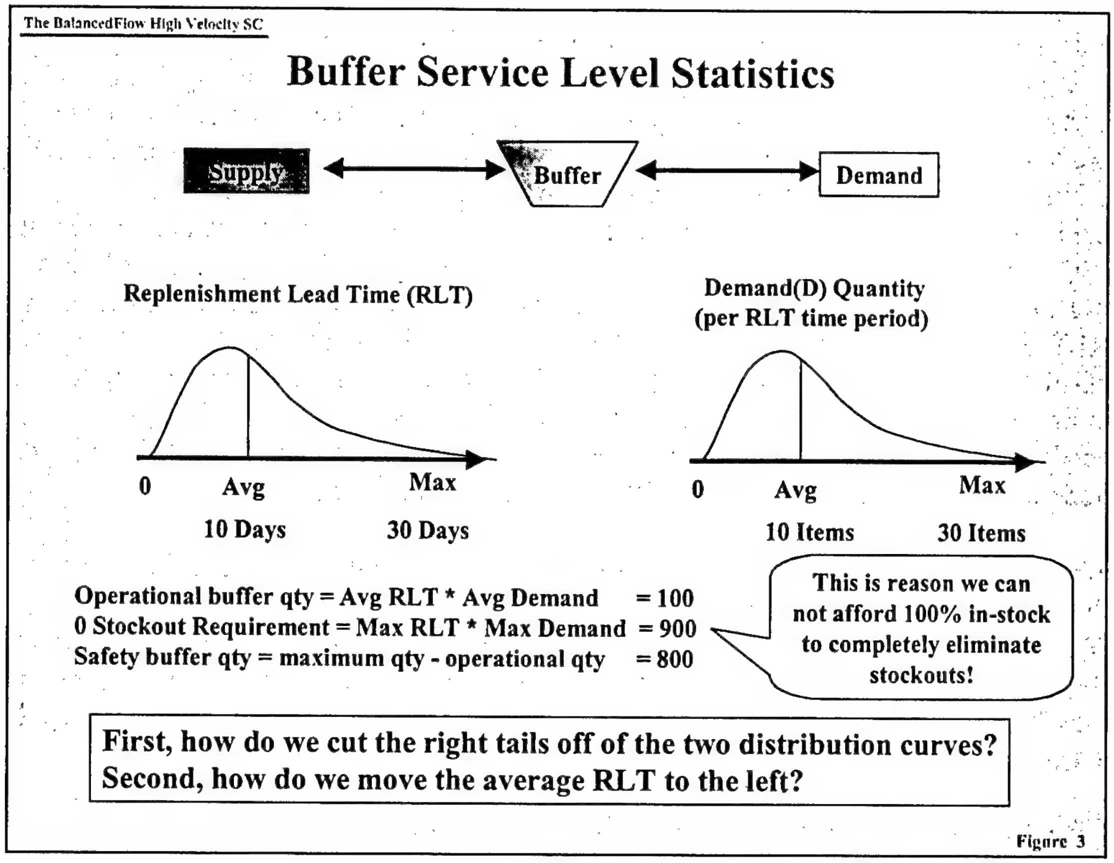

Figure 3 – Buffer Service Level Statistics

The RLT distribution curve (in replenishment days) is always strongly skewed to the right because there is a practical limit of "0" time to the left and no limitation to the right. The specific problem that this distribution presents is that we do not know which order will fall at the end of the right tail so we must carry buffer stock to protect every item and every order from the longest RLTs if we want a one-hundred percent service level or zero stockouts. The consumer demand distribution curve (in average items demanded per RLT period) is also somewhat skewed to the right because demand can not go below "0" to the left and there is no limit to the right.

Let's use some typical, but conservative replenishment and demand numbers to develop our example. If the average RLT is 10 days, the longest RLT will be 30 or more days. If the average daily demand is 10 items, the typical highest daily demand will also exceed 30 items.

The operational buffer requirement of 100 items is the product of the average RLT and average demand per day. This means that we need 100 items in stock to cover the average daily demand of 10 items while we are waiting on a replenishment order that will take the average 10 days. If we wanted to avoid all stock outs, we would have to stock 900 or more items in our buffer (the product of the maximum RLT and maximum daily demand). The safety level is the difference between the maximum requirement and the operational requirement. This indicates that to go from a service or in-stock level of about

50 percent, to a service level of 100 percent, we would have to increase our buffer stocks by almost an order of magnitude! This is why it is too costly for retailers and others to achieve a 100 percent service level. Most settle for an 80 percent goal and do well to operate in the low 70s. Can we not do better?

7.3 The Specific Steps that enable the BalancedFlow Magic

Now that we know the parameters and statistics that determine the service level, let's examine the two distribution curves and determine what we must change about them to achieve minimum stock outs at minimum buffer levels for a single generic buffer. For the RLT distribution curve, we want to shrink the right tail and move the average to the left. For the demand curve, we want to shrink both tails ***while moving the average to the right***. In addition, if we reduce the RLT variation and average and shrink the tails of the demand curve, we will move the average demand to the right through increased service and reduced costs!

The following figure shows every possible way we can go about shrinking the tails and reducing the average RLT for each of the three buffer components.

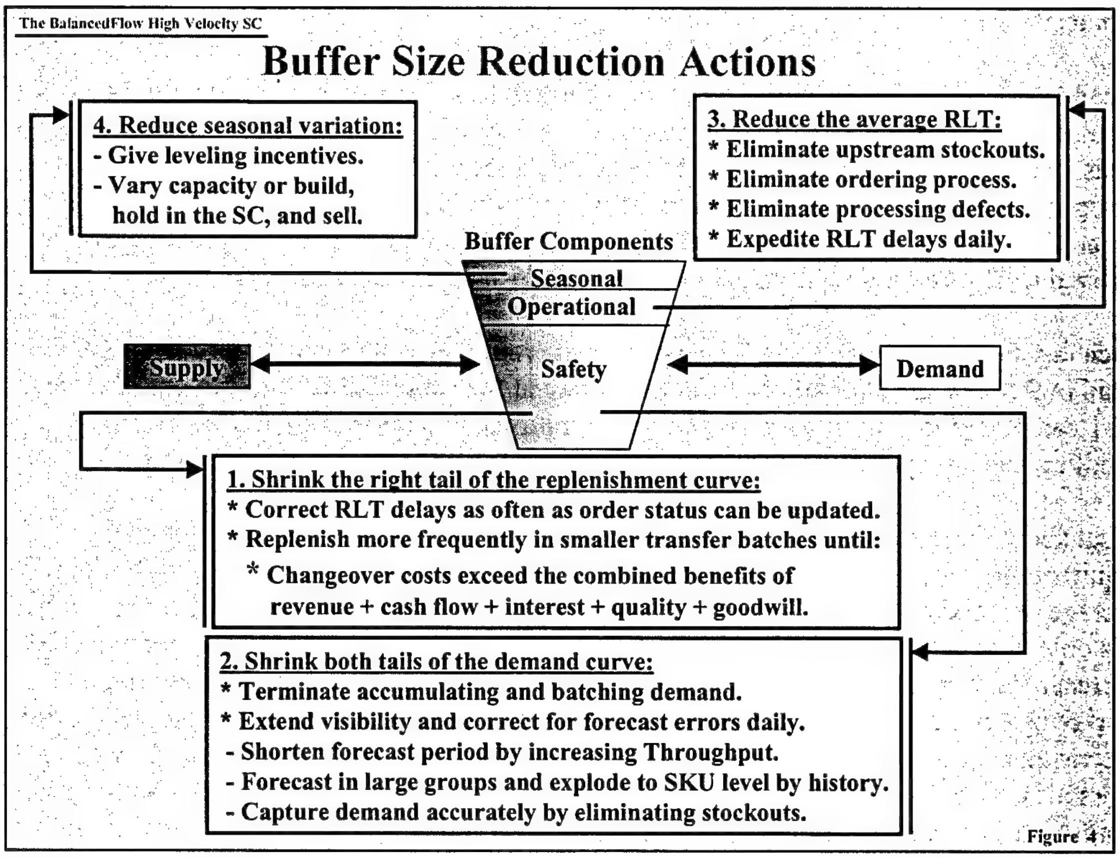

Figure 4 – Buffer Size Reduction Actions

7.4 Decreasing the Safety Level Requirements

The right tail of the RLT distribution curve can be reduced by acquiring replenishment order status as often as possible (daily is most likely available) and establishing a

flagging routine to draw attention to those orders that have a high probability of falling in the right tail. Expediting then can be applied to the very small percentage of all orders that have a high probability of falling in the right tail. This will significantly shorten the length of the right tail. In addition, when this process is first initiated, a Pareto analysis will lead appropriately to assignable causes of delay that can be eliminated. Eventually, the only few remaining outlying points will be due to random variation and expediting can pull these back to the left. This technique requires finding that fine balance between taking unnecessary exceptional actions so early that the "system" would have resolved them in time through the normal course of business and so late that there is insufficient time to prevent the downstream stock out.

The right tail of the RLT distribution curve can also be reduced by replenishing as frequently as possible in as small batches as possible. If one batch gets delayed, others are probably in process and may arrive in time to prevent a stockout. This also means that available replenishment stocks can be retained upstream for flexibility and allocated out to meet minimum needs when there is an overall shortage in the SC. Then no downstream customer can order a large quantity that they do not need and starve other customers until capacity is regained. However, there is a practical limit to how frequently replenishment can occur.

Frequent replenishment requires small transfer batches. Small, frequent transfer batches require more changeovers upstream and downstream with their associated batch handling costs. More frequent changeovers should be made until the combined improvements in revenue, cash flow, INV investment, quality, and goodwill no longer exceed the costs of the additional changeovers. At this point the optimum replenishment frequency has been reached ***until changeover costs can be reduced by world-class teamwork***.

Each day that we remove from RLT permits the removal of a day of supply from the retail buffer and the SC will continue to operate at the same risk of running out of stock. RLT can be reduced until the changeover operational expenses of increased batch handling and transportation costs exceed the benefits of TT and INV reductions.

What about the demand curve? Can we do anything to modify it to lower the buffer requirements? Since our overall business objective is to increase total demand (move the average demand per day to the right), we need to be careful that we do not conflict with this objective as we try to reduce buffer requirements. Our specific buffer objective is to decrease the variation in daily demand quantities. For our retail example, anything marketing can do to shrink the tails of the demand curve would be helpful. However, this is consumer demand and the major source of demand variation is often created by sales promotions. Looks like the overriding objective of increasing total demand is actually a major cause of demand variation! This is correct for the demand placed on the system by the consumer, ***but we are not yet seeing the complete SC picture properly.*** It is not the consumers' demand that impacts the SC, but what the retailer does with consumer demand that matters most to the rest of the SC!

The consumer holds a unique and very special position in any SC. Each process owner up the SC should take actions based on the demands that the consumers place on the last process in the SC in contrast to the batched demand placed by the downstream SC segment. However, at many segments in the SC we find some type of administrative replenishment process that translates the flow of incoming demand to less frequent and larger batches of outgoing demand. ***This is where the trouble starts.***

In our example, the retailer translates consumer demand into replenishment orders that are sent up the chain as shown in the following figure:

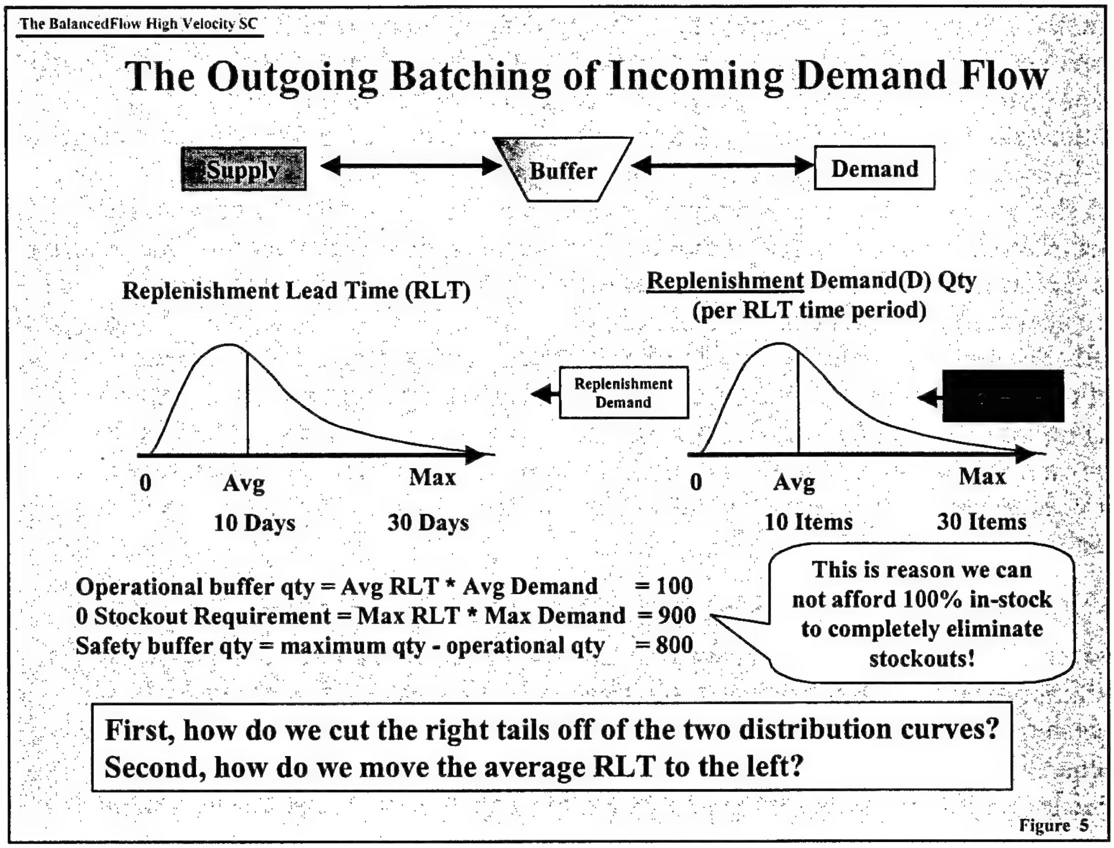

Figure 5 – Infrequently Batched Replenishment Demand

Now that we have a common replenishment demand curve rather than the unique consumer demand curve, we can define the general case that applies to all buffers instead of the special case of consumer demand. All replenishment systems batch the incoming flow of demand into less frequent and larger quantity replenishment orders. The effect of this batching on the SC can be compared to a professional cowboy using a bullwhip. The handle that the consumer is holding moves up and down very slowly, but each foot down the whip incoming demand flow is batched into outgoing demand until the gating process owner at the beginning of the SC finds himself at the tip of a very fast moving whip. The handle and tip move up and down the same number of times, but the tip has to move many times faster to cover the much greater distances in the same amount of time.

Each day of demand that we push from the tails of this replenishment distribution curve back into the center of the curve has the same impact on the SC as taking a day out of RLT. Thus, ***the initial power to improve the SC begins not at all with the consumer or manufacturer, but with the retailer***. In fact, retailers can change the way they generate replenishment orders and take time and inventory out of the SC much easier and faster than the manufacturer can take time and inventory out by removing a day through reduced RLT. ***The down-stream SC partner holds the key to start the improvement, but the upstream partner holds the power to multiple the amount of improvement!***

7.5 Decreasing the Operational Level Requirements

Again, the operating level requirement is the product of the average RLT and the average demand per RLT period. We know we do not want to decrease the average replenishment demand (only its variation) so we are left to focus on decreasing the average RLT. First, all actions discussed earlier to shrink the right tail of this curve also reduce the average RLT. In addition, sufficient inventory must always be in the next upstream buffer from which the downstream buffer is replenished to eliminate any possibility of covariance. Replenishment demand and RLT covariance is the worst possible situation. This occurs when replenishment demand is increased artificially because of the expectation or fear that replenishment will take an exceptionally long time. This artificially high demand can actually drive the upstream buffer out of stock and cause buffer's RLT to increase significantly. Therefore we must replicate our buffer management practices at every buffer up the SC so all RLT variations are due to variations within the replenishment system and not to out-of-stock situations upstream. More importantly, we must craft our BF implementation strategy in a manner to completely eliminate the fear of running out of stock.

7.5.1 Minimum Buffer Requirements in the Best Conventional SC

However, as discussed earlier, we want to convert all buffers behind strategic processes to minimum-sized transfer batches to optimize TT. This means the next available replenishment buffer will be some distance up the SC and will not be able to respond immediately with the delivery of new product. Therefore, each strategic buffer replenishment module ***must*** contain a method of flagging potential stockout situations in time for exceptional actions to result in replenishment from the next available upstream strategic buffer before the stockout actually occurs.

This knowledge leads us toward the answer of how much we must stock in a buffer. It must be enough to permit the detection of a potential stockout problem and receive expedited product from the next upstream buffer. Appears this would be about three times the amount normally within the SC between the upstream and downstream buffers. We could check when two-thirds of the time has passed, detect shortages, and still have just enough time to receive new stock from the upstream buffer to avoid the stockout.

However, the key to making this happen is to transfer ownership of the process to the owner of the upstream buffer. At best, the downstream buffer owner can only signal the problem – only the upstream buffer owner can fix it. This requires a significant change both in responsibility and action.

7.5.2 Minimum Buffer Requirements in a BalancedFlow SC

But wait, what we have just described is the very best way of operating replenishment modules in conventional SCs! BF is anything but a conventional SC. If we launch daily new work that is needed most from ***every*** strategic buffer, we automatically have most of our demand variation covered – no matter what causes the variation. In the worst case scenario, we could discover all of a particular product is defective within a buffer and back upstream to a particular process. The day we remove the defective items from the SC, BIFRS takes immediate corrective action at ***every*** upstream buffer to replenish the removed items. The process causing the problem is most likely between the empty and next upstream buffer so some non-defective product is most likely already flowing down the SC. So the question is not how much should be in the downstream buffer, but how much should be in the upstream buffer to match risk of a downstream stock out to inventory carrying costs!

The worst case answer is the minimum stockage required to feed the most constrained process between the empty buffer and the next upstream buffer until the entire SC can be re-balanced sufficiently to eliminate the possibility of stockouts in the target buffer. Since reaction is immediate, all attention and productive capacity are shifted immediately to the problem items, and some usable INV is most likely in downstream SC segments, only a small amount of INV is required in the replenishment buffer. In fact, it is a fraction of the INV required in the very best conventional SCs.

7.5.3 Eliminate Existing Replenishment Processes

We should eliminate both traditional and more modern replenishment ordering processes from the entire SC and shift completely to BalancedFlow. The existing replenishment processes are non-value added, contribute to higher INV and OE, and take time to execute (and the time required to execute requires equivalent buffer coverage). In addition, if the replacement of defective items slows the RLT process, Six Sigma techniques should be employed to eliminate the defective items and uncover the hidden factory as well. Finally, automatic checks should be established in the order fulfillment process to ensure all data-handling transactions are in fact necessary (especially manual ones) and that they occur as scheduled. If there are any exceptions, they should be flagged and the causes of the exceptions should be corrected.

7.5.4 The Simplicity and Power of a Few Strategic SC Segments

Our understanding of strategic BalancedFlow and SC segments is now becoming much clearer. Only a very few SC segments with buffers require replenishment (all other segments work next on what arrives next) and these are our strategic SC segments. The replenishment signal can come from anywhere within the SC by a drop in INV, but automatic and immediate corrective action is initiated from above and extends up the entire SC. This is why our total high-level focus can work through our very few strategic SC Segments!

7.6 Decreasing the Seasonal Requirements

An analysis should be conducted to determine the true nature of what appears to be seasonal and promotional variation. Variations caused by other than seasonal or

promotional needs should be eliminated. Seasonal peaks can be leveled to some extent by price incentives, but this only goes so far.

This leaves us with the choice of either modifying capacity to meet seasonal demand or creating a buffer of seasonal stocks to protect both the retailer and manufacturer. In practice a combination of seasonal buffer INV and modified capacity normally provide the optimum solution to seasonal and promotional demand variations. BIFRS provides the capability to create and execute an optimum seasonal and promotional demand strategy within the SC.

7.7 Shrinking the Tails of the Statistical Curves and Reducing the Average RLT

In summary, BIFRS was specifically designed to shrink the right tail of the RLT distribution curve, reduce the average RLT, shrink both tails of the retailer's replenishment curve (while increasing the average demand) and properly managing the seasonal demand. The remainder of this document explains in detail how each of these actions is accomplished.

8. Supply Chain Science (How the SC's Building Blocks Interrelate)

Now that we have developed our knowledge of how individual buffers work, lets step up to the question of the relationships between all SC buffers, processes, and consumer demand. If we can define these relationships in mathematical terms, we will be approaching our goal of establishing the tools to optimize our entire SC. Let's begin with basic definitions.

8.1 Supply Chain Components

A SC is uniquely defined by its items, segments, and movement batch sizes:

(1) ***Items*** are the individual products produced by the SC. They are normally identified by stock keeping unit (SKU) numbers at retail and BF retains this item identification convention for uniformity across the SC. SKUs are the lowest level part numbers assigned to individual items at a given segment within the SC. These identification numbers may change as the items take on transformations as they travel down the SC. SKUs move down the SC in transfer or process batches.

(2) ***Segments*** consist of storage buffers and work processes as shown earlier in Figure 1.

(a) ***Buffers*** are inventory on-hold that is between processes waiting for activation on the next process. Strategic buffers are value-added buffers that protect the consumer, permit distribution flexibility, protect the internal constraint, and protect the gating process. All others should be reduced to minimum transfer batches.

(b) ***Processes*** are resources that convert inventory from one physical form to another or relocate inventory. Processes are further defined within BF as constraints or non-constraints and as value-added or non-value added. Value-added processes are those that change the physical make-up of the product, are requested and paid for

by the customer, or are required by law. All others should be eliminated or conducted in parallel rather than sequential.

(c) ***Strategic segments*** consist of up to five pairs of processes and their supporting buffers that BIFRS uses to optimize the performance of an entire two-company SC through constraints scheduling. They are the external and internal constraint segments, the distribution segment, the scheduling segment, the gating segment, and legacy scheduling. The buffer in the final strategic segment of a defined SC is referred to as the "target buffer" (TB) because the BF SC is designed primarily to maintain the prescribed target level in the terminal SC segment. When a third company is added to the SC, another internal constraint, distribution process, scheduling process, and gating process are added for the third partner. BIFRS is simply replicated as many times as needed.

(3) ***Batches*** consist of groups of items that are moved together between buffer and process segments or across processes. Batches consist of single or multiple items and can be either process or transfer batches.

(a) ***Process batches*** are the groups of items that move sequentially across processes until a changeover is required. The number of individual items that are moved across a process between ***changeovers*** determines the process batch size.

Changeovers are extremely important activities to understand and leverage within the SC. Increased changeovers ***can*** result in higher product costs and lower SC-wide capacity. However, additional changeovers ***can*** also be a huge profit multiplier through increased revenue and lower SC-wide costs. The impact of changeovers on the SC's goal can only be accurately determined through constraint management techniques. BIFRS is designed to maintain top-level management focus on TT as ultimately limited by changeovers.

A group of individual items with minimum changeover requirements between items ***on the constraint process*** is normally called a manufacturing style or some kind of production group. BIFRS designates each of these lowest-changeover families of items as a specific production group code or PGC.

(b) ***Transfer batches*** are the groups of items that move together from one SC segment to another. The number of individual items that are moved as a group between SC segments determines transfer batch size. Reducing replenishment order and transfer batch sizes and replenishing more frequently reduces buffers.

8.2 BalancedFlow Supply Chain Model

The SC must be broken down into sufficient detail to isolate the strategic processes. The strategic processes and buffers for a manufacturing through retail SC are shown with red in the following figure:

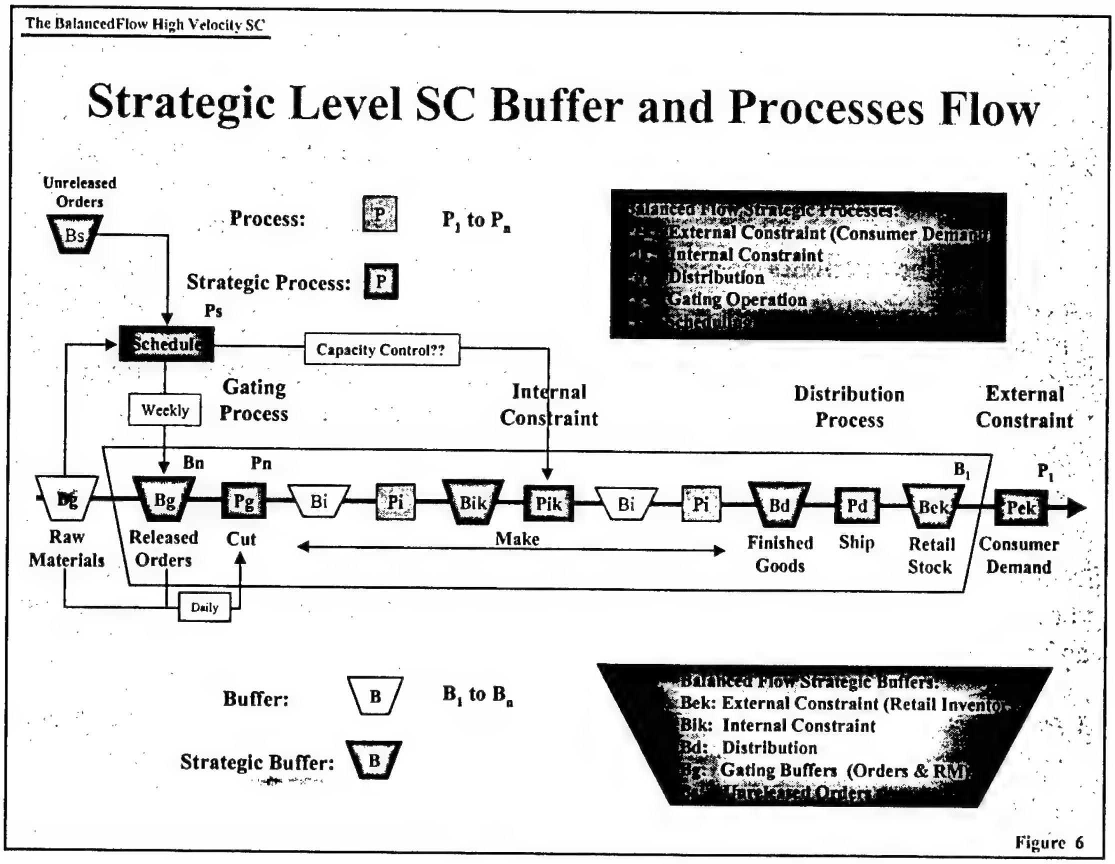

Figure 6 – Strategic Level SC Buffer and Process Flow

A defined SC can have any number of segments and two to five strategic segments. For example, a very basic SC could include the target buffer of finished goods, the constraint segment, and the gating segment. Another example could include the target buffer of retail stocks and the shipping process including its raw materials of finished goods. A common, basic three-segment SC within a manufacturing plant consists of finished goods, work-in-process and unreleased orders connected by a scheduling process.

The ideal SC for constraints-based scheduling consists of an external target buffer, a distribution segment, an internal constraint segment, a gating segment, and BIFRS scheduling.

The complete BF SC for end-item manufacturing as shown above begins with the terminal or external constraint buffer (Bek) that supports the terminal or external constraint process (Pek) and moves back upstream to the gating process (Pg) and gating buffer (Bg). The legacy scheduling process (Ps) with its buffer of unreleased orders (Bs) is included because it controls the flow of new orders into the physical SC and actually is part of the SC when it is not totally parallel to the SC. The BF SC extends to the internal constraint (Pik) and internal constraint's buffer (Bik) when Pik is stabilized and the number of items on BIFRS are sufficient to have an impact on the constraint's workload. Finally, if there is any type of distribution from a distribution center or just from finished goods, BIFRS includes the distribution process (Pd) and buffer (Bd).

There are actually two gating buffers within the SC as shown in Figure 6. The scheduling process that is shown generates the "rough-cut" schedule and the final scheduling process is actually located between the released orders buffer and cutting process. The rough-cut or master schedule should consider the capacity of the internal constraint (Pik) as well as the availability of raw materials.

The gating process owner must have both released orders and corresponding raw materials to generate the final, detailed gating schedule. The raw material buffers are directly in the physical flow of the SC, but the legacy process of rough-cut scheduling fills the buffer of released orders. Hopefully, legacy scheduling was designed to fill the buffer of unreleased orders with firm customer orders or INV replenishment orders at the rate that the internal constraint can process the work (and in a sequence to maximize process batch sizes on the constraint). Often however, legacy scheduling no longer workloads the constraint because it has moved and, in almost every case, legacy scheduling operates much less frequently than either consumer demand or detailed scheduling. Herein lies the primary opportunity for the BF concept within manufacturing – ***scheduling consumer-driven demand very frequently on the real constraint.***

Not depicted above is the process flow of demand generation that terminates with Unreleased Orders. This is the part of the enterprise that uses OCTANE to generate new orders for the SKUs that generate the greatest contributions to cover OE and profits.

If the segments selected are only within a manufacturing operation beginning with finished goods, the BF system is not a SC driver, but a very effective constraints-based scheduler that can be extended easily to drive the entire SC. The terminal process in a complete end-item through manufacturing SC is the transfer of the items to consumers and the gating process is the introduction of new raw materials into end-item manufacturing.

When the SC is extended upstream to raw material manufacturing, the gating buffer moves all the way upstream leaving the old gating process of end-item manufacturing as just another strategic buffer within the SC.

8.3 The One-to-one Relationship of Time to Inventory connects SC Segments

A SC can be described in terms of the time it takes an order to move from raw materials to the consumer. It can also be described in terms of the quantity of inventory that it contains within its segments. Both of these measurements are determined by summing the individual quantities at each individual buffer and process (the time it takes an order to cross each buffer and process or the quantity of inventory residing on each buffer and process). If we can define the link between time and inventory quantity, we can expand greatly our understanding of and ability to control SC operations.

Manufacturing computations frequently use the term production lead-time (PLT) to describe how long customers have to wait for orders to be manufactured, but PLT does not connect time to capacity or item quantity. However, logisticians think in terms of how

long a quantity of supplies will last or "days-of-supply" (DOS). In fact, the Army has long used the DOS concept to build and balance war reserves of vastly different products on a common basis. The common denominator for each product is the number of days that the available quantity is expect to last once consumption begins at a defined rate. Using this concept, war reserve stocks from food to fuel can be built up evenly so in wartime everything will last approximately the same number of days. This specifically minimizes the risk that scarce funding will be invested in one product (e.g. 90 days of fuel) while another product goes under funded (e.g. 30 days of ammunition). The wartime results of an unbalanced SC are obvious. ***This is our defined connection between time and item quantity and it most appropriately originates with the consumer.*** The consumers define the relationship between time and quantity based on the manner in which they place demand on the SC.

It is obvious that every process owner in the entire SC should be working as hard as possible to satisfy consumers. Therefore, we need to define a link that ties each strategic SC process owner directly to consumer demand so each process owner knows what to work on next. Consumer demand can be expressed in quantities of a SKU per day. In fact the capacity of every SC process can also be expressed in quantities of a SKU per day and, over a long period of time, the average daily capacity should equal the average daily demand. If we use the different SAHs that each product requires on each process, we can still match demand for many different items made on a single SC to the capacity of every process within that SC. With the addition of SAHs to the average daily demand concept, we have our complete mathematical links between time, quantity, processes, and buffers!

We define a DOS as the average daily ***consumer demand***. In fact, if we use annual demand we can define one annualized average calendar day of supply as 1ADOS and now we have a consumer-driven measurement and conversion factor that permits us to think and conduct calculations in days of supply rather than item quantities.

1ADOS = Forecasted Demand / 365 Days

A 1ADOS quantity provides a much higher level of information than a single time or quantity measurement plus it permits us to link the performance of every buffer and process across the SC.

Lets now describe some of the many different computations that the 1ADOS opens for us. First is the direct and one-to-one connection to our TT (one annualized average day of supply equals one day of TT). We can now express TT as either time or quantity for the entire SC or a single buffer or process. When we bring in SAHs for each different SKU, we can compare buffer or process capabilities for any mix of different SKUs for a defined SC. Knowing that over a long period of time (such as a year) each SC process should have an average capacity equal to average consumer demand, we can easily compute the average daily capacity requirements. Finally, when we know the 1ADOS and the SAHs required by the constraint, we can convert promised hours of capacity on the constraint to the same number of hours of new work on the gating operation. This

permits us to accommodate both "A" and "V" production lines. These relationships are profound for bringing simple constraints-based scheduling to reality.

When we sum all of the individual SKU 1ADOSs and adjust from calendar days to workdays, we have the initial daily capacity requirement for the production line. In fact this recommended capacity is the only link between our BIFRS SC targets and all other BIFRS computations. The plant scheduler begins BIFRS by assigning production capacities very close to the total 1ADOS requirement (adjusted for plant work days), monitors SC performance through the BIFRS TT Management Chart, and makes surgical-like capacity modifications to adjust SC on-hand DOS performance to SC DOS targets.

If we use our 1ADOS to compute the capacity of each of our production line processes, we identify the constraint and other bottlenecks in very meaningful terms. We can use this measurement to insure we have sufficient constraint and protective capacity. We can easily change product mixes and run "what-ifs" to see the impact on our production line. If the top few bottlenecks have close to the same capacities based on our 1ADOS, we do not have to shift our constraints-based scheduling based on a shift in the constraint! If differences are large, we can see the change in constraint processes coming and take appropriate action to shift the focus of our constraints scheduling.

We also know from our review of SC statistics that the SC consists of a series of sequential and dependent segments with statistical variations within every segment. These variations do not average out, but the negative variations are additive. For example, late order completion from one segment carries down the SC and the lateness is not eliminated downstream because another order is completed early by the same amount of time. This statistical variation across dependent SC segments is the underlying science that supports our use of constraints management across the entire SC.

8.4 Standard Allowed Hours connect Consumer Demand to Strategic Processes

TP, direct labor costs, and capacity are all based on speed and evaluated by time measurements. TT in the form of PLT is the most important manufacturing speed measurement for SC optimization. However, the cost of direct labor time is the most used and miss-used measurement within manufacturing. Capacity is the third time measurement for manufacturing and its miss-use also offers great opportunities for SC improvements.

8.4.1 Direct Labor Cost Measurements

Manufacturers have perfected local cost reduction at the expense of fast TT for the entire SC. Slower TT minimizes direct labor costs while increasing INV, cost of quality, and stockouts. TT and INV are two sides of the same coin in that they are directly related by the rates at which batches move. To increase TT simply means reducing buffer and transfer batch sizes. As introduced above, value-added processing times are so small across a SC that they normally can be ignored without consequence. For example, the average value-added-SAMs for a shirt are about 25 minutes, but the complete traditional

manufacturing TT for a shirt is 4 to 6 weeks! Total SC TT for a shirt is about 16 months from fiber to consumer purchase. The INV and OE costs including the quality and handling of these inventories must somehow find their way into the retail price of the shirts.

The way in which SAHs were originally (and are still) used is a root-cause problem of poor SC performance. Piece rates were originally used universally for individual pay computations so performance against SAHs was readily available in the form of ***efficiency***. Today the direct labor and overhead numbers are reversed, but accounting still makes the same arbitrary assignment. This often leads to erroneous management decisions because direct labor is no longer the manufacturing constraint and different items clearly are not responsible for the same relative amount of overhead costs.

The original acceptable cost accounting convention of spreading overhead evenly over direct labor was adopted by management and is totally entrenched as the most important management metric for productivity. The results is that every process must be operated as efficiently as possible every minute to "cover or consume the budgeted overhead" irrespective of the need for the output. Changeovers are to be avoided at all costs (even though they increase profitability) because they reduce local efficiency. This is local optimization at its worst because each process should be producing what the SC needs the most, not more items that are already in long supply.

Because of local optimization, individual process owners are responsible only for direct labor costs as measured by efficiencies. No one within the manufacturing community is directly responsible for or has the tools to minimize inventories or stockouts. In fact, inventory interest costs normally make their way to the bottom line of the profit and loss statement with no internal ownership. Finally, no one within the SC has responsibility for or control of stock outs at retail just as no one within manufacturing has responsibility for or control of inventory costs. ***In reality, the <u>owners of the five strategic processes</u> within the SC can control the SC's stockouts, capacity, and inventory expenses through the proper application of constraints management.***

8.4.2 Manufacturing Capacity and Scheduling Measurements

On the positive side, SAHs are the ideal metric for managing the SC's most precious and scarce resource – the manufacturing line – and the constraint process on the manufacturing line. SAHs permit managers to compare one item directly to another in terms of profitability and required manufacturing resources. When manufacturing capacity is limited (and it always is) every effort should be made to sell the maximum number of items that have the highest contribution to profit per SAH on the most constrained process (our OCTANE calculations). This approach to optimum profitability is seldom undertaken because standard cost accounting is the basis for item pricing and sales incentives are usually based on price and/or cost accounting's erroneous "marginal contribution to profit."

When work-loading the plant with items that have different SAHs, schedulers must make decisions in terms of SAHs, not in terms of the quantities of each item. In fact, schedulers

must workload the process (and only the process) that has the most limited capacity, because the plant can produce no more than this constrained process can produce. In fact, the scheduling process can be simplified greatly by real-time monitoring of only the strategic SC segments and frequently scheduling only the internal constraint process. Scheduling non-constrained processes results in expediting, increased WIP inventory, late deliveries, and missed sales. Thus, TOC provides the focus for SC throughput optimization for both the sales and manufacturing organizations.

8.5 The Power of Reducing 1 Day of PLT and Eliminating 2 Days of SC Inventory!

Remember, we have been thinking in terms of the retail buffer of our SC, but a reduction in RLT or a reduction in replenishment variation applies in the same manner to every buffer across the entire SC. In fact, ***a day taken out of an upstream segment such as WIP also permits the removal of a second day of supply from downstream buffers.*** The SC will still operate with the same risk of stockouts with these two days removed because of the faster response time. We can then respond to customer needs two days faster (which further reduces stockouts) and remove two days of inventory at the same time. This is a huge goal multiplier and the key to drastically reducing inventories across the entire SC. Clearly, we now see how to improve service levels while reducing inventories and lowering manufacturing costs. However, we need the SC partners to work together to unlock this power and realize the benefits.

8.6 Supply Chain Constraints

A constraint is defined as the process currently causing the largest bottleneck in relation to the SC's goal of increased profitability. A SC can have only one overall external or one internal constraint at a time. Different processes can constrain the SC to levels so close to each other that it is difficult to distinguish the constraint from other large bottlenecks. Over long periods of time the SC's constraint moves from the external location to an internal process and back to the external location. When the constraint is external, demand is less than capacity and there is excess capacity. When the demand is greater than the internal constraint's capacity, there is a conflict between the constraint of customer orders and the internal constraint. In this case action must be taken to resolve the constraints or some orders will be delivered late.

The performance of the constraint process is dependent on the performance of previous processes as well as its own statistical variations. The statistical variations on each process do not average out as the order moves down the manufacturing chain – the negative performance is cumulative! In addition, work builds in buffers of non-constrained processes for short periods of time because they have other work ahead of the latest arriving order. However, over a period of time, by definition, non-constrained processes have more capacity than the constrained process and will run out of work. If these two situations did not exist, we could just schedule each order according to their SAHs with appropriate batch handling times, release them into manufacturing, and they would be completed the length of their SAHs later.

8.6.1 The External Constraint

There is only one external constraint to the entire order fulfillment SC and it always should be consumption – the SC partners can only sell what the consumers are willing to purchase. If too little is available, sales are missed. If too much is available, inventory costs and operating expenses are high. Each internal segment of the SC should be driven primarily by the rate of consumption at the very end of the SC, but the SC's internal constraint ***must*** be driven primarily by the external constraint.

Consumption is defined in this manner to highlight the difference between the consumption process, which almost always involves one item at a time, and the replenishment process, which normally involves a batch of items at a time. The consumption process is unique in that it occurs only once at the terminal point of the SC. However, replenishment is a part of every SC segment SC beginning with the terminal or consumption process. Replenishment accumulates the flow of incoming demand and transmits it up the SC in batches.

8.6.2 The Internal Constraint

The SC can have only one internal constraint at any given time because the SC consists of a series of dependent events or segments, each with statistical fluctuations. This constraint is simply the internal process that is the largest bottleneck ***in relation to the SC's goal***. The constraint moves around as new policies are implemented, as attempts are made to balance the plant, and as production mixes change. The constraint may be an artificial policy anywhere in the SC or a natural physical constraint within the order fulfillment system.

Since the goal of the SC is increased profitability, the current constraint can be ***anything*** that constrains the attainment of this goal. However, a SC has only one natural or physical internal order fulfillment constraint and it is the process segment (resource) that would cost the most when purchasing one step up in SC ***capacity***. This natural constraint should be identified, promoted, held constant, and used to optimize the entire SC. (Initially, all artificial policy-driven bottlenecks that are larger than the natural constraint must be identified and a decision must be made either to eliminate them or to select one by which to run the entire SC as a surrogate for the natural constraint.)

8.7 The Relationship between Throughput and Capacity

The following figure uses the three middle buffer-process segments extracted from Figure 6 to show the full relationship between throughput and capacity:

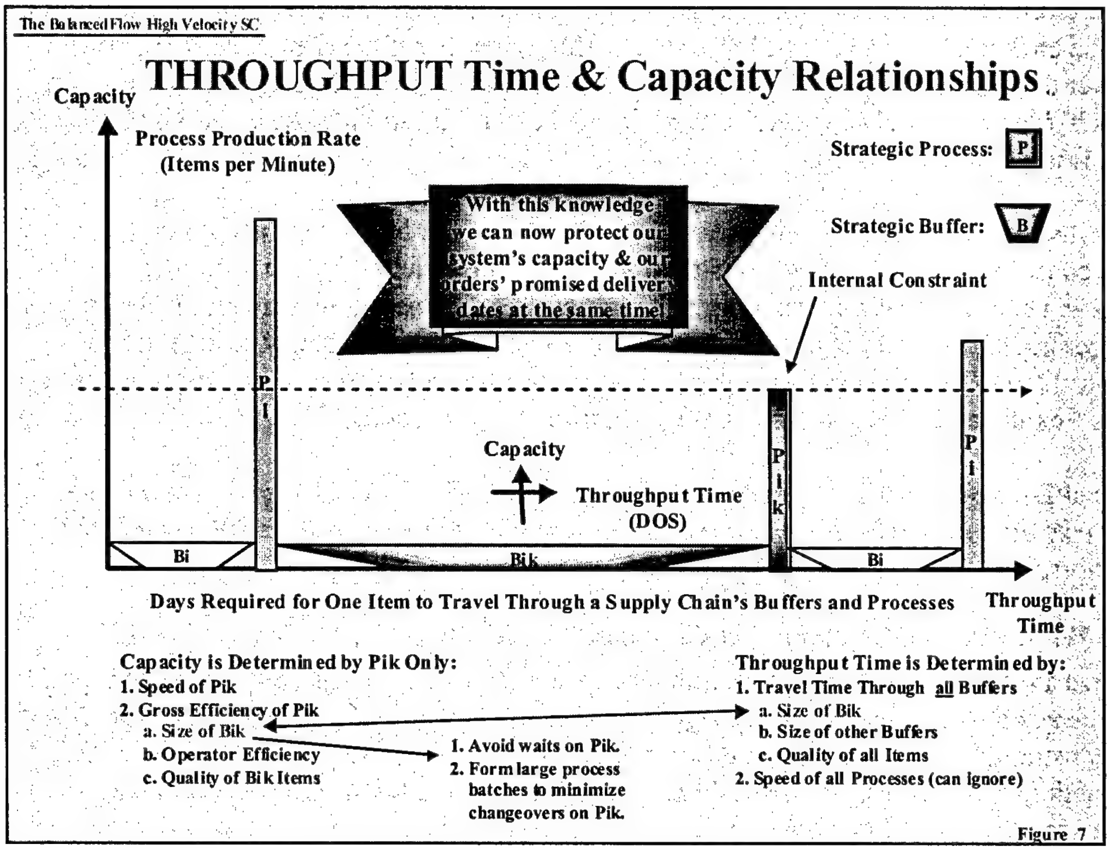

Figure 7 – Throughput and Capacity Relationship

TT is posted on the *X*-axis in days and capacity is posted on the *Y*-axis in items per minute. All orders and individual items must pass through all buffers and processes of the SC. Thus, individual buffers and processes extend from the left to the right with their lengths depicting how long it takes for an item to pass through each. Most process times are so short (seconds or minutes per item) in comparison to buffer times (hours or days per item) that they can be safely ignored. Bik is the largest buffer here because it must protect the constraint. In contrast, the other two buffers should only be minimum-sized transfer batches.

Since process Pik has the lowest capacity, it is the constraining process and it determines the capacity of the entire SC. The size of every individual buffer contributes to the total throughput time, but only the size of the constraint's buffer contributes to capacity. In addition, the constraint must have upstream protective capacity so it never runs out of work. This means upstream processes must have higher production rates than the constraint, the constraint's buffer must last long enough for the upstream processes to replenish it if there is a major disruption of production, and there has to be an upstream buffer from which replenishment can originate. Upstream SC velocity or replenishment leadtime (RLT) is critical to the replenishment of the constraint's buffer and is the key determinate of the size of the constraint's buffer.

Therefore, the only place at which capacity and throughput objectives directly conflict is at the constraint's buffer. The larger the buffer, the higher the SC's capacity and the lower the changeover costs (larger buffers offer more opportunities to increase process batch sizes which reduces changeover-driven costs). The smaller the constraint's buffer, the faster the SC's throughput.

Downstream inventory requirements are also determined by the size and composition of the constraint's buffer. If the constraint's buffer is insufficient in size or process batch mix to keep the constraint running at a high gross efficiency, downstream buffers must be larger in order to protect against disruptions at the constraint. Clearly, it is better to protect the SC with more inventory in the constraint's buffer than downstream where it is less flexible and where it is incurring higher interest expenses.

For this unique buffer, capacity and downstream INVENTORY requirements take priority over throughput up to the point at which process capacity is fully protected because this is the SC's constraint segment.

8.8 What Evidence is there that Constraints Exist in a SC?

There are a number of indicators that serious constraints exist and these indicators point to the actual constraints. If a SC segment has stockouts of incoming products, something is constraining the replenishment process. If there are large buffers of work in the SC, something is constraining their movement forward. If manufacturing requirements vary to a greater degree than consumption, something is constraining the flow of demand up the SC. If there is any expediting in the SC (and especially on the production floor) something is constraining the accuracy of legacy forecasting and scheduling. Finally, the most serious indicator of a constraint is the existence of backorders. This means something is constraining timely customer satisfaction.

8.8.1 Scheduling Non-constraints creates Expediting!

Anything can be the internal constraint and the internal constraint may be moving about constantly creating chaos! Most scheduling systems were originally properly based on scheduling the internal constraint, but seldom does the internal constraint stay fixed. There are many forces constantly operating to change its location – not just the routine problems and delays encountered on the production line. These forces can be policy decisions that once optimized local SC segment performance, but at a greater (and often unrealized) cost elsewhere in the SC.

In addition, managers almost always exert great effort to balance their plants, resulting in the chaos of a constantly moving constraint. Since it is impossible for a plant to remain in balance, a schedule based on a balanced plant can not be maintained. When the SC's internal constraint is not the constraint being scheduled, the SC does not perform according to the needs of the external constraint (needs of the customer) and "expediting" becomes a normal part of the management process to limit backorders. In fact, some companies even have people whose job titles are "Expeditor."

8.8.2 Expediting Costs are Hidden and High

It is not unusual for production managers to spend over half of their time expediting high priority work. This is so highly accepted that it is considered a normal job duty and a solution to, rather than a symptom of, SC problems. Expediting is non-value added and extremely costly in many ways. It increases production lead-time, consumes managers' time, increases changeovers, requires additional space, increases WIP inventory, delays the discovery of quality problems, and frustrates production line operators resulting in reduced productivity. Eliminating expediting significantly lowers item costs and increases throughput.

BIFRS schedules the natural constraint and eliminates expediting. The production line can then eliminate processes associated with expediting and lower OE. Expediting is an obvious measurement of SC sickness and it is followed closely by its close relative called "backorders."

8.8.3 Backorders are Indicators of Sickness

Backorders are normally one of the critical measurements that senior managers carefully watch because they provide the insurance that all resources will be fully employed to "earn" or "consume" all the overhead that has been allocated to the various processes in the annual budget. In reality, backorders are measurements of (1) customer frustration, (2) the risk that competitors will take away the business, and (3) the opportunities for increased profitability and future security if the trading partners are willing to establish a BF SC.

8.9 The Multiplying Benefits of a Simple SC Partnership

It is most interesting to realize the limitations of conventional SCs in which the retailers and manufacturers do not share profit-multiplying data, but haggle over the last penny of item price. The RLT distribution curve as well as PLT is under the ownership and control of the manufacturer. Only the replenishment demand curve belongs to the retailer. In the normal non-partnership SC, the manufacturer can shorten PLT and take the speed and inventory expense reduction benefits through finished goods. This puts the manufacturer in a better position to respond faster and/or lower prices. However, manufacturers seldom accept the perceived risk of increased operating expenses that are required to reduce PLT without certainty that some additional revenue will actually materialize. They need a partnership to guarantee minimum additional revenue once they respond faster.

On the other hand, most retailers have never seriously though about the possibility of achieving benefits from sharing their inventory status with manufacturers frequently or from cutting the ends of the tails off of their replenishment demand curves. Each time that a retailer provides the manufacturer with asset visibility, the manufacturer's "feast or famine" production demand curve is dampened and item costs go down. In addition, most retailers employ ancient replenishment systems that extend the tails of their replenishment curves by creating batches of consumer demand and replenishing infrequently ***which is exactly the wrong action to take***. This means that there is essentially no possibility of dampening the manufacturing demand curve or achieving reduced PLT, improved RLT, or an improved retail replenishment demand curve when

retailers work in isolation and at cross purposes to manufacturers. However, when retailers and manufacturers form SC partnerships, the two together can easily take advantage of all three areas with certainty of additional revenue (reduced stockouts), lower inventories, and lower manufacturing costs. It appears retailers hold the overall key and need to extend the first invitation to a partnership.

There are many reasons as to why SC partnerships have never really worked in spite of the promise of increased profitability. Major problems are the entrenched drive for local optimization, the absence of timely and accurate forecasts, the absence of total asset visibility, and the lack of a practical supply concept and supporting engine.

The BF concept and the BIFRS' constraint-based SC engine offer a solution to all of these problems based on the very best science-based management concepts and automation technologies. Most importantly, BF can bring partners together with a concentrated focus and, in a minimum investment of time and cost, have the SC up and running. In fact, it is feasible to demonstrate the benefits of BF on the first family of items in just one day.

10. The SC Partners set the SC's Basic Inventory Objectives as DOS of TT

After the SC partners define their SC in terms of segment flow and SKUs, they next determine appropriate targets for each buffer in days of supply (DOS) and process in production leadtime (PLT). The sum of these individual targets is the total for the entire SC. The targets can be expressed in terms of TT or inventory quantity since they are two sides of the same coin and linked by our 1ADOS conversion factor. We generally use DOS to describe these targets. The partners should initially establish the targets at current operating levels. Later, when we have total asset visibility and the BF concepts are fully understood, the partners can begin to improve TT by slowly reducing the inventories in the buffers.

BIFRS uses the term basic inventory objective (BIO) to designate a stable inventory requirement without any consideration for seasonal or promotional needs. The retail partner sets the retail BIO, the partners agree on the intransit BIO, and the manufacturing partner sets the BIOs for the buffers and processes within manufacturing.

Except for the BIO for the target buffer, there are no direct mathematical links between the BIFRS requirement calculations and the BIFRS goal calculations. The target buffer BIO is used within BIFRS for calculating the upper limit for SC actions. The target buffer BIO is also used directly as a target on the TT Management Chart. The connection between targets and requirements is the constraint capacity assigned to BIFRS items for each BIFRS cycle.

All of the individual BIOs are summed and this is the SC BIO. If there are seasonal or promotional variations in demand, we have to compute a seasonal inventory objective or SIO. This is computed from the demand forecast or demand history.

11. The Demand Forecast

BIFRS uses the best available forecast to compute the 1ADOS, the 1RDOS, and the SIO. When a forecast does not exist, a history of demand is satisfactory. We would like to totally eliminate the forecast because of the inherit problems with forecast error, but we can not do this and have items in stock to instantly gratify consumer demand. Therefore, the BF system trivializes the importance of the forecast. This permits us to approach a 100 percent service level with reduced inventories rather than the normal requirement of increasing inventories by an order of magnitude to approach a 100 percent service level.

11.1 BIFRS trivializes the Impact of Forecast Error

A demand forecast is required so items can be produced ahead of time and made available for each consumer's instant gratification. Since the forecast is an estimate, it is always either too high or too low. When the forecast is too low sales are missed and this is the most costly error. When the forecast is too high inventory costs are very high. The longer the forecast period, the less accurate the forecast. The more detailed the forecast, the less accurate the forecast. The only way to overcome forecast error traditionally is to stock large buffers at high excess stockage costs. Legacy replenishment systems link stockage objectives and replenishment frequency. The higher the stockage, the less frequent and the larger the replenishment orders. There are complex conventional risk assessment and costing tools to address these issues. However, BIFRS simply shortens the forecast period and uses the SC's resources in a manner that absolutely minimizes the impact of forecast error. Errors are detected and corrected automatically down the SC as often as inventories are updated and scheduling corrects for all forecasting errors and inherit variation as often as it can be conducted.

11.2 BIFRS connects the SC Segments with 1 Annual Day-of-supply (1ADOS)

The 1ADOS is the forecasted annual average number of items that will be consumed per calendar day by the external constraint. This number is used to convert buffer quantities to days-of-supply (DOS) so BIFRS can balance different items with different quantities, different production rates, and consumption rates in DOS. This makes the risks of stockouts and excessive inventories equal for all items over the annual demand cycle.

The manufacturing and wholesale partners are primarily concerned that manufacturing capacity plus SC inventories are available to meet forecasted demand over the next year in order to cover seasonal and promotional demand variations with lowest possible inventories and level manufacturing. This long-term view is the reason for beginning the SC calculations with one annualized average day of supply as the primary forecast quantity. The 1ADOS total for the entire SC is the sum of the individual average annual daily demands for each SKU in the SC.

However, this 1ADOS does not work for the retail partner if there is seasonal or promotional demand because retail objectives by priority are (1) meeting shorter-term consumer demand (2) with minimum inventory.

11.3 BIFRS replenishes Retail with 1 Retail Day-of-supply (1RDOS)

DOS (days-of-supply with no implied consumption rate) has a different meaning for the retail partner if the consumer demand pattern is not random. At retail, DOS are based on the length of time the retail buffer will last at the near-term forecasted rate of consumption by the external constraint. The retail partner is specifically concerned that retail inventories consist of sufficient DOS to meet demand just beyond retail replenishment leadtime (RLT). Stated differently, the critical retail buffer should vary in size based on the near-term consumer demand so that the risk of stockouts is minimum and constant all year. For the retailer, the 1ADOS is either too high or too low for almost every day of the year.

For this reason 1ADOS is used to designate one annual average DOS and 1RDOS is used to designate one average DOS based on a closer-in or "local" retail time period. BIFRS can use the 1RDOS forecast (rather than the 1ADOS forecast) to replenish the retail buffer. The retailer's DOS target remains constant and is based on a number of calendar days as is 1ADOS. Thus, the distribution process simply alters retail replenishment to correspond to forecasted demand just beyond replenishment leadtime (RLT) and, modifies accordingly, the shipping velocity of seasonal inventory.

11.4 BIFRS levels Production Needs with Seasonal Inventory Objectives (SIOs)

BIFRS breaks the annual forecast into weekly time periods to establish seasonal and promotional demand patterns. If there are no seasonal or promotional patterns, the SC is linear and we do not have to deal with seasonality.

When the demand pattern is seasonal (or promotional), the manufacturer has to either adjust capacity to meet demand or build inventory during low demand to meet high demand later. A third and most common alternative is the combination of both. Some seasonal inventory is built and capacity changes support the seasonal requirements that are not covered by inventory.

BIFRS' initial SIO computation is based on level weekly manufacturing all year long so a base case of seasonal inventory requirements can be computed. In this situation, seasonal inventory must be made and stored during low-demand periods so it is available for consumption during high-demand periods. Therefore, SIOs are computed for each week of the year and added to the basic SC requirements to establish a SC total inventory objective (SC TIO) for each week of the year. Weekly time periods were chosen primarily to match the norm of weekly scheduling.

If the manufacturing partner desires to modify capacity to meet the seasonal demand, BIFRS simply reduces the SIO by the percentage that the manufacturer desires to cover.

12. Drum-Buffer-Rope (DBR) Constraints Scheduling

BIFRS is pure constraints-based scheduling. Demand originates from the target buffer at the end of the defined SC daily and is received by every strategic process owner within the SC daily as a steady drumbeat of what to process next. This is our steady drumbeat of demand and it consists of a daily frequency and an average daily demand of one DOS.

All of the inventory in the SC resides on the processes or in the buffers that exists to protect each process from adjacent processes. Finally, the rope is the BIFRS software that connects each strategic process owner with the drumbeat of demand.

In contrast, legacy scheduling has no semblance of drumbeat and no rope tying the consumer (who is the most important process owner and SC driver) to all other process owners. However, the SC driven by current forecasting through legacy scheduling does have buffers of inventory – about 90 percent more than is needed located in all the wrong places!

12.1 The Drum drives Each SC Process through the Strategic Processes

The primary "***drum***" that produces the drumbeat to which each segment of the SC ***should*** operate is the external constraint of consumer demand (frequency and quantity). The secondary "drum" ***is*** the plant schedule, but a combination of legacy forecasting and the receipt of large, infrequent customer orders drive the schedule. Then, everyone attempts to meet the schedule in spite of expediting that is introduced frequently to correct for forecasting errors. In fact, the consumer's demand (which is the most steady and predictable demand of the entire SC) is consolidated and batched through every SC process until the gating process owner feels like the tip of a bullwhip that is being slowly and gracefully exercised by the consumer.

BIFRS is a replenishment process that captures the consumer drumbeat and passes it to every other process owner in the SC in a manner that makes the bullwhip totally ineffective.

12.2 The Drumbeat Frequency is Daily

The primary drumbeat sounds each time a consumer places a demand on the SC and it is normally unrealistic to begin by expecting to match the internal drumbeat to this frequency. However, there is another natural, but less frequent external drumbeat that is ideal for driving the internal manufacturing drum. It is the daily aggregated consumer demand. This is almost always available after daily batch runs, but is seldom recognized or used up the SC. The schedule should be based primarily on this daily drumbeat of the external constraint, but also on the forecast of future demand, the amount of each item currently within the SC, the target amount of each item within the SC, and raw material availability. Legacy-scheduling systems for manufacturing fail to reflect any meaningful semblance of the ***consumers***' drumbeat. BIFRS restores the drumbeat to scheduling and also to every SC segment through the SC's strategic processes.

12.3 The Drumbeat Quantity is established as One Day of Demand

The ultimate consumer's daily drumbeat of demand is almost always for a quantity of one. For example, the technician who uses a repair part on a machine only consumes one part at a time. However, he may start the batching bullwhip by carrying a few on his tool cart and replenishing from the stockroom infrequently when he thinks about it or runs out of stock. Even if our SKU is direct material rather than a repair part, it is removed from the final buffer and consumed one physical unit at a time.

Obviously the SC can not order, manufacture, and deliver batches of one item immediately each time there is a single demand at the final point of consumption. The partner at the end of the SC does not have the means of passing a demand of one up the SC instantly each time the demand occurs nor can the order fulfillment process respond economically in units of one in most situations. Since we have established the ideal drumbeat to be daily from retail, the corresponding drumbeat quantity is one actual day of supply. ***We now have three different daily quantities that must eventually, over a sufficient period time, equal one another!***

These three different forms of daily demand are (1) our forecasted 1ADOS, (2) our one average day of manufacturing requirements, and (3) our actual one-day of demand. With these three different DOS in hand, we can totally eliminate the bullwhip effect through BIFRS. We initially set our constraint's capacity to equal our 1ADOS forecast. Then, on a daily basis, we capture and use actual demand to adjust what we process next at each strategic process. (We also can use this daily demand through our forecast to adjust automatically our 1ADOS, SIO, 1RDOS, and thus our target quantities.) We can then hold our manufacturing capacity level and see if our balanced on-hand days of supply are gaining on or moving away from our targets. If the differences move together or apart in the same direction for 8 consecutive periods, we need to adjust capacity ***slightly***.

Now, back to the specific issue of drumbeat quantity and how to use this to evict the bullwhip from our SC. Our drumbeat DOS can have any number of SKUs for any quantity per SKU. Again, we clearly can not respond in this manner. Therefore, the challenge is to first determine the optimum buffer and batch size for our strategic processes and then to use our daily demand to synchronize the optimum SKU mixes and quantities to rebalance our SC from each strategic process forward daily. This does not mean we have to take action daily at any strategic process based on actual daily consumption. It does mean we check every day at every strategic process to see if we have attained the batch-size or action threshold.

The action threshold is determined by the cost-benefit based batch-size parameter values we set for each strategic process. For example we may not want to break cases at distribution or we may want to consume a complete physical unit of raw material if we have to load the physical unit into production for a small quantity order.

12.4 The Single SC Buffer is Managed Through Strategic Segment Buffers

BF is about strategic buffer management. Unlike traditional process improvement methodologies, BF focuses almost entirely on buffers rather than processes because this is where the vast majority of the opportunity for radical improvement resides. Lets begin this section by reviewing the behavior of inventory in conventional SCs based on what we have learned so far about supply chain science.

There is really only one buffer in a SC and it consists of the entire inventory within the SC. This inventory exists (1) to protect the ultimate consumer from stockouts, (2) to protect all value-added order fulfillment processes from the bullwhip effect created by downstream demand batching, and (3) to permit production in large and "efficient"

batches. The obvious constraints to traditional SC process owners are stockouts of incoming materials and low efficiencies of production line processes. The results are the same. In response to stockouts of incoming materials, they take the logical action of stocking more, but someone soon realizes they can not afford to stock enough to eliminate the problem. In response to the possibility of low efficiencies, production line managers have to keep making something even if it is not needed to "consume the budgeted overhead."

Meanwhile, the extra inventory introduced into the SC continues to pile up behind artificial and natural bottlenecks (the largest of which at any given time is the SC's constraint). Policies and consumer demand are both in constant change that, in turn, cause the bottlenecks to be constantly moving. Just as "expeditors" attempt to correct for inadequate scheduling on the production floor, every SC process owner becomes an "expeditor" in an attempt to correct locally a system that is totally out of control. Each process owner creates shadow tools and processes to work around the existing management system to make their expediting more efficient. These tools and processes become institutionalized adding to our opportunities for improvement. Why have manufacturers permitted this behavior to continue? The answer is in our improper use of cost accounting to drive operational decisions. Let's review this problem before we get to the corrective action.

Inventory is almost never created on purpose; it is the unintended or unseen fallout of locally optimized financial or disjointed operational decisions. Since inventory seldom has a specific owner, it exists largely unnoticed except for its impact when it slips quietly to the bottom line of the Profit and Loss Statement through "Net Interest Expense." In fact it disguises itself very well as an asset on the Balance Sheet and thus picks up a few very strong advocates in the financial community. In addition, its actual physical presence on the production floor, in the finished goods warehouse, and neatly filling retail shelves gives production workers, salesmen, and retailers warm and comfortable feelings. Production workers know that low upstream inventories will result in layoffs, salesmen want as much finished goods inventory as possible because it might meet immediate customer needs, and retailers want full shelves to make the best possible visual impact on shoppers as they view the merchandise. Inventory is not deliberately created, has no specific owners, is a huge barrier to our goal of profitability, but taking it away causes predictable emotional trauma for many people.

BalancedFlow implementation cuts to the heart of the primary problems exhibited by traditional SCs. It synchronizes all process owner's actions with consumer demand through the SC's real constraint thereby eliminating the need for all of the extra shadow processes, excessive TT, excessive INV, and excessive OE. It is implemented through world-class teamwork to optimize improvements, create ownership, and remain in place.

Once the internal constraint and the other strategic processes are identified, the focus of all BIFRS action turns to the strategic management of the SC's single buffer. Meanwhile, on the production line, a separate, but coordinated BalancedFlow effort should be

underway to fix the constraint in place and reduce changeover times on the constraint process through world-class teamwork.

We intend for the inventory within the SC to accumulate behind a very limited number of strategic processes in strategic buffers. All the other buffers should be reduced in size until they only contain a minimum batch transfer quantity. We can control the entire SC by monitoring the inventory in these few strategic buffers and initiating actions on upstream processes based on the movement of product off the end of the SC and through these buffers. For an end-item to retail SC, the strategic buffers supply the strategic processes and are:

(1) The external constraint's buffer of retail stocks (the target buffer in our example).

(2) The distribution process's buffer (when distribution decisions are made after production is completed).

(3) The internal constraint's buffer once the constraint is located and fixed in place.

(4) The gating process's buffer of released, but non-processed production orders.

(5) Scheduling's buffers of unreleased orders and raw materials.

The implementation of BIFRS changes the priorities of the work in each strategic buffer daily to ensure strategic process owners always select next the work that will turn into cash the fastest.

The constraint's buffer is there to protect the due dates of the individual orders plus the capacity of the constraint. The only way to provide this protection is to release orders earlier than they would be released based only on their SAHs and due dates. ***The cumulative effect of these early releases, the statistical fluctuations, and the non-constraint delays accumulates in the buffer behind the constraint!*** If we release every order one day early, we would expect to average just less than one day's work in the constraint's buffer. (Remember, positive and negative variations do not average out – the bad accumulates and is passed on downstream.) If the buffer tends to be dangerously low, we need to increase the early release time. If the buffer tends to be too high, we need to decrease the early release time. Here again, we must make decisions in units of time and later convert this time into quantities. The conversion factor must be and is our 1ADOS supported by different SAHs of different items.

The constraint is actually protected by the early release of orders. This early release accumulates in the physical buffer behind the constraint to protect each order and the capacity of the SC. Therefore, the protection has two required components – the physical buffer and the "extra" or protective capacity to refill the buffer should it be drawn down. If upstream production is interrupted, the buffer will be reduced to keep the constraint running and protect the capacity. Once the problem is resolved, the upstream non-constraints must have sufficient protective capacity to refill the buffer to the desired level

before production is interrupted again. This means we must retain extra resources upstream of the constraint and stop them from producing when the constraint's buffer is filled. In contrast to traditional manufacturing, we can not let these processes be driven by demands for efficiency!

12.5 The Rope connects Consumer Demand to All Strategic Processes via the Constraint

The "***rope***" is the BIFRS software that synchronizes the work that strategic process owners select next from strategic buffers to the drumbeat of consumer demand. The drumbeat can be continuous in real time or it can be periodical such as weekly or daily. BIFRS' software first uses the operational parameters defined by the SC partners and total asset visibility (TAV) to compute the next requirements (unreleased orders) for scheduling. This re-balances the entire SC as frequently as new work is scheduled for the gating operation by the legacy system. It also computes the quantity of each item that should be immediately placed into production at all the other strategic processes including distribution. This eliminates the core problem of large, infrequent orders that create the bullwhip effect as well as all of the non-value-added ordering processes for each strategic process.

BIFRS is the rope that re-balances the SC from each strategic segment forward each time new work is initiated, thereby maximizing the re-balancing velocity all the way to the consumer in concert with the drumbeat of the external constraint. In other words, brakes are applied to over-forecasted items and acceleration is applied to under-forecasted items immediately across the entire SC. This is the first critical stage of BF in which stock outs are eliminated, but the average item velocity is not yet increased. Average velocity is increased later in the second stage of BF when buffers and transfer batches are reduced in size.

BIFRS' constant re-prioritizing of released orders to rebalance and add velocity to the highest demand items across the entire SC contrasts sharply with traditional scheduling and goes one step further than classical TOC. Rather than requiring manufacturing to take every possible action to meet the original due dates established by the schedule, ***BIFRS automatically and immediately changes the job order priorities based on changed downstream consumer need and production line variations so everyone works next on the items most urgently needed.***

12.6 Why Non-strategic Processes are not Scheduled

Non-strategic processes should not have intentional buffers (only transfer batches) because buffers slow throughput, increase inventories, and increase operating expenses. However, there is a need to maintain buffers and work them down slowly when BIFRS is initiated. Seasonal (or promotional) inventory, if required somewhere within the SC, should not reside on non-strategic buffers.

Processes that have no choices of what to work on next do not need a schedule. They simply must work on the next item that is available and stop work if no items are available. BIFRS does not schedule non-strategic processes.

13. Buffer and Batch Sizes Determine Total Throughput Time

Buffer and transfer batch sizes determine TT or the velocity at which an order moves from one end of the defined SC to the consumer at the opposite end. Each order must pass through multiple buffers and batches as it travels down the SC. Movements from buffers to processes take place in transfer batches. Movements across processes take place in process batches. In fact, transfer batches act as small buffers when we break the SC down toward the last level of detail. The smaller the transfer batches the faster the process TT and the smaller the buffer; the faster the buffer TT. Since we desire the fastest possible TT, what limits us from going immediately to buffers and batches of one? The response has two parts – we must protect the constraint since it controls SC capacity and we must be sure increased changeover costs do not outweigh all the combined benefits of shorter TT.

A constraint's buffer has to be large enough to protect the constraint from starvation and large enough to generate reasonable-sized process batches. This protects the capacity of the enterprise as well as the promised dates of the individual orders within the buffer. Each non-constraint's buffer should be reduced to the point that the process does not quite become the constraint, but retains the minimum required protective capacity.

13.1 Changeover Costs Limit Buffer and Batch Size Reductions

Operating expenses increase through increased changeover costs and labor efficiency losses as ***process*** batch sizes become smaller. We can cut TT on a single process in half by cutting the ***transfer*** batch size in half. However, we now have to acquire, open, process, close, and dispose of two batches for every original batch. This is an additional, low-cost changeover the first time we do it, but it becomes extremely costly as we move toward transfer batches of one item. Changeover costs may even exceed processing costs as processing batches become smaller.

If we can group similar items into large process batches, we have fewer high-cost machine changeovers, but we pay a penalty in increased downstream inventory stockage. We can increase process batch sizes on the constraint with scheduling and with larger buffers just before the constraint process. Both methods increase inventories, but TT is best controlled if this is accomplished first during scheduling and refined slightly later on the production floor in the constraint's buffer based on downstream demand changes. This is exactly what BIFRS accomplishes.

As buffers and batches become smaller, operators have to move to other processes. These move times and lower efficiencies on less familiar processes result in lost capacity in addition to increased labor costs. At some point the further reduction of changeover costs requires a move toward or to the full Toyota production system to minimize these changeover costs. However, this introduces other increased costs such as capital investment in more machines and space.

On the following chart THROUGHPUT time (TT) is the speed at which INVENTORY (INV) is converted into cash. INV consists of raw materials and other inventory that is consumed or converted through value-added processes. OPERATING EXPENSES (OE)

are all the costs of converting inventory into new money. The chart shows the relationship between batch sizes and profitability considering TT, I, and OE:

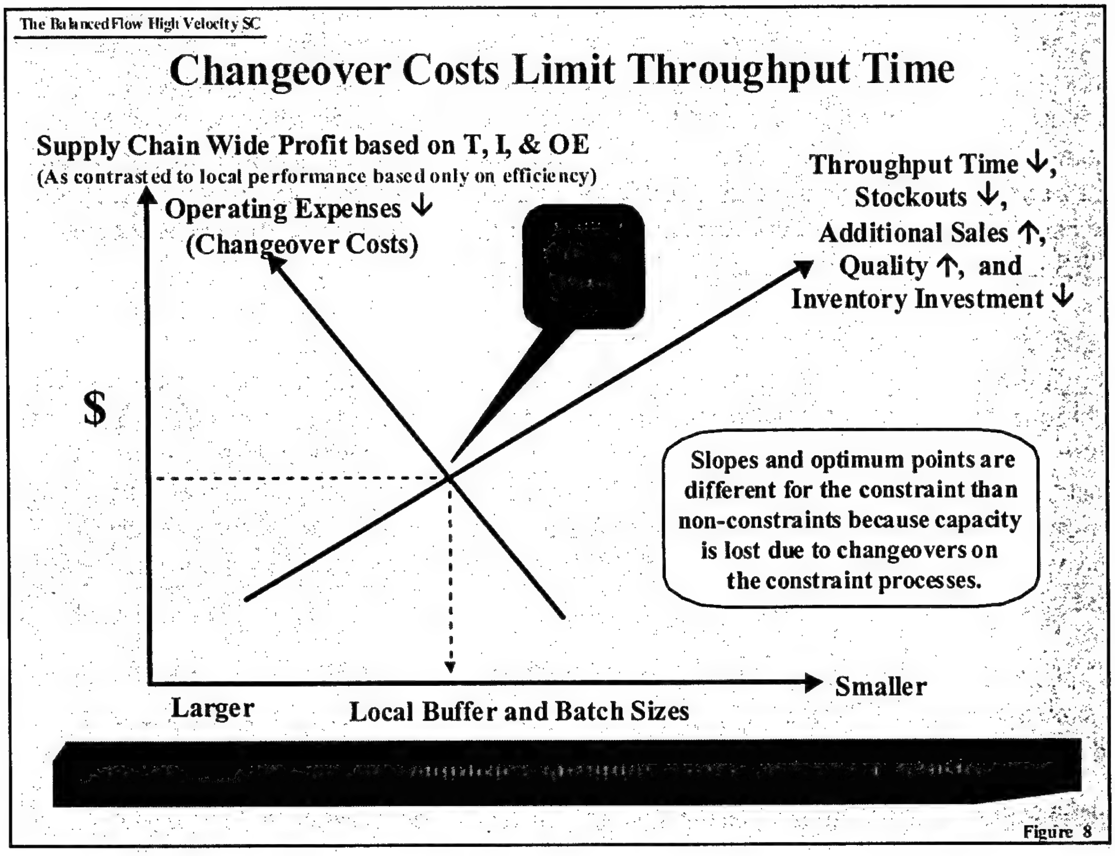

Figure 8 – Optimum Buffer and Process Batch Sizes

BalancedFlow computes the two curves and determines the optimum buffer and batch sizes. Optimum sizes of individual buffers become smaller as the SC is brought into sufficient balance to protect the external constraint and as the overall velocity of the SC is increased.

Buffer sizes are controlled through order release times, process batch sizes are controlled during scheduling, and transfer batch sizes are deliberately and directly set. There are great opportunities for improving each of these because the buffer and batch sizes either "just happen" or were set long ago to optimize local performance or administrative needs.

13.2 The Essence of Long-term Supply Chain Optimization

Since changeover costs limit the reduction of transfer batch sizes, it is extremely important to focus initial manufacturing improvement efforts on the largest bottlenecks. First, the SC's natural constraint must be located and all larger bottlenecks must be removed. As soon as the natural constraint is identified, the first world-class process improvement team must be charged with reducing the changeover time on the constraint

by 50 to 90 percent. (The complete and proper application of fast-turn methodologies will attain up to 90 percent improvement in Throughput.)

As changeover times are reduced, transfer batch sizes can be reduced, thereby enabling even greater enterprise-wide improvements in TT and capacity. However, a strong warning is made at this point concerning the constraint. Reduction of changeover time can increase the capacity of the constraint process to the point that another process becomes the new constraint! When this happens, another world-class changeover team must be assigned to work the changeover time on the new constraint. In addition, if the new constraint has significantly less capacity than the old on the existing product mix, BIFRS must be modified to schedule the new constraint.

BIFRS forces frequent and correct enterprise-wide actions by all strategic process owners through the most important operational measurement of TT. The second most important operational measurement, INV moves in the correct direction as a direct link to TT. Improvements in these two measurements are limited by the third most important measurement, OE, in the specific form of changeover costs on the constraint. Once rising changeover costs limit the continuation of TT and INV improvements the primary improvement effort must be passed back to the manufacturing floor with a focus on the constraint's changeover time.

Each time PLTs are reduced in manufacturing, the SC partners must decide where to take the same amount of TT out of downstream buffers. ***These cycles continue indefinitely and they are the essence of continuous process improvement.***

13.3 Non-strategic SC Process Segment Optimum Batch Sizes

As batch sizes become smaller, operating expenses go up because there are more batches to handle and more changeovers. The costs of additional batch handling and changeovers must be determined because they increase OE and reduce profit. On the other hand, as batch sizes become smaller, work-in-process (WIP) is reduced thereby reducing inventory, inventory investment, and the cost of quality. The WIP inventory reduction is converted into cash on a one-time basis and the inventory interest that is avoided becomes profit for as long as the inventory remains out of the SC. However, this is only the beginning of the impact on the entire SC!

For each day of inventory removed from WIP, PLT is shortened by a day. In addition, a day of inventory can be removed further down the SC with no change in the performance of the SC. Therefore, the value of removing one day of PLT is the sum of the value of the WIP and the full value of a day of finished goods. There are still other benefits.

By far the greatest benefit occurs when sufficient PLT is removed so that customer leadtimes can be met by beginning with raw materials. A small portion of the inventory savings from faster throughput can be invested in additional raw materials and customers can be offered vastly expanded choices plus the SC can react to new customer demands much faster. The impact of this can be huge on profitability because operating expenses are already covered. If the SC is meeting the established business plan and covering all

OE, the profit from the sale of one additional unit is essentially the unit price less raw materials and any other direct costs. This is the source of funding monetary recognition for a strong team-based incentive program that encourages optimum efficiency on all processes, no matter how much work is upstream.

13.4 Constraint Process Segment Optimum Batch Size

There is an additional factor to consider when reducing process batch sizes on the internal constraint and there is a conflict with the external constraint of market orders. A constraint operates just like a non-constraint concerning PLT and OE. Smaller batches increase batch handling and changeover times. However, since the constraint determines capacity for the entire SC, production time lost (when orders exceed capacity) on batch handling and changeovers, is lost sales to the consumer! Time lost on a non-constraint can be made up, but not time lost on the constraint. On the other hand, production time gained on the constraint is increased capacity for the entire enterprise. This is why constraints management and changeover time reductions on the constraint are so vital to the enterprise.

13.5 Process vs. Transfer Batches

Again, there are two kinds of batches; process and transfer. Process batches are groups of items that are processed between changeovers. Transfer batches are groups of items that are moved together from one SC segment to the next. For example, a transfer batch of 12 blue shirts could be placed into production followed by another transfer batch of 12 white shirts. If the same thread color were used and no other changeovers were required on the process segment, the process batch would be 24 shirts. The SC-wide batch-size objectives are to have transfer batches as small as possible and process batches as large as possible. Therefore, scheduling must release some additional orders early to increase process batch sizes on the constraint if changeover costs are significant and there is a conflict with the external constraint. Additional inventory is justified when it protects capacity, but it should be located as far upstream as possible to also protect flexibility. It must be located behind a natural bottleneck or one (such as holding in place until distribution decisions are made) will have to be created.

13.6 Costs of Reduced Batch Sizes

It is important to recognize that process batches may consist of one or more transfer batches when optimizing throughput on a process. It is also important to realize that changeover requirements can range from insignificant to major. A bundle changeover as described above is so minor it is normally not thought of as a changeover for apparel manufacturing. A thread changeover requires more time, a machine setup requires even more time, and retraining is the most costly type of changeover.

Finally, the cost of a changeover includes the operators' loss of productivity as well as the time required to complete the changeover. Some amount of time will be required for the operator to return to standard productivity after a changeover and an estimate of this loss must be included in the costing process. Thus, there are two components of this changeover loss; operator productivity and SC capacity. All changeover costs must be

determined and compared to all the benefits of faster throughput. ***This analysis must determine the net affect on the SC's goal through each of the four objectives.***

13.7 SC Segment Type and Location Implications

When determining optimum batch sizes for a particular SC process segment, it is very important to understand the type of process segment and its location within the SC. As discussed previously, strategic process segments are the external constraint, the internal constraint, the distribution process, and the gating operation (which may be the internal constraint). Other SC segments are non-constraint processes with unintended buffers.

13.8 Optimizing Buffer and Batch Sizes

The BF System contains a Replenishment Optimization element that computes optimum buffer and batch sizes from historical demand data, replenishment lead-times, and financial parameters.

13.8.1 The Internal Constraint Determines SC Capacity and Profitability

Total SC capacity is determined by the capacity of the internal constraint – no more can be sold than can pass through the constraint. Capacity, throughput, and operating expenses are a trade-off only at the constraint. BIFRS is a real-time constraints scheduling program that is extremely simple to run. It provides the driving performance measurement of TT in a manner that leads managers to the current constraint with minimum effort. TT is increased as inventory is taken out of the SC. The limits to inventory reduction at first are policy constraints, but these can be rather quickly identified and eliminated by top management. Soon, operating expenses in the specific form of production batch changeovers on the constraint process become the constraint to further inventory reductions and TT improvements.

Actually, BalancedFlow gives clear trade-off choices never before available. Remember that the changeover limitation occurs when one more changeover costs as much as the resulting benefits from fewer stockouts plus inventory reduction. Since the implementation of BalancedFlow eliminates stockouts in the target buffer, we can forget about it in our decision equation. Now we only have to compare changeover costs to inventory carrying costs ***while maintaining sufficient inventory to eliminate stockouts***. If the changeover costs are higher than inventory carrying costs, we need to increase the downstream inventory. If the changeover costs are lower, we need to do the changeovers. If the answer is to carry more inventory, we know exactly which SKUs to carry first (OCTANE) and how many to carry (TT).

Be cautious at this point because modifying the number of changeovers can cause the constraint to relocate just as quickly as changing the production mix.

13.8.2 Non-constraints Upstream of the Constraint

If the process segment is between the gating operation and the constraint, it must be active only for the minimum time required to keep the constraint's buffer adequately filled. Incentives should be in place to keep the production rate as high as possible and overcome the natural tendency to slow down when there is a reduction of work upstream.

The process must be stopped when the objective is reached or it will build excess inventory downstream prior to the constraint process and it will eventually starve itself if new work is being introduced properly at the gating process.

13.8.3 Non-constraints Downstream of the Constraint

If the process segment is between the internal constraint and the last internal process, it must be active only for the minimum time required for it to empty its buffer. Incentives should be in place to keep the production rate as high as possible and overcome the natural tendency to slow down when there is a reduction of work upstream. The process segment must be stopped when its buffer is emptied and resources assigned to other activities with priority given to cross training to the constraint first and other bottlenecks next.

13.9 Replenishment Optimization Computes Optimum Buffer & Batch Sizes

Larger buffers and transfer batches increase opportunities for larger process batches that lower changeover costs. However, larger buffers and batches increase inventory investment costs and lengthen TT, which, in turn may decrease sales. In addition, strategic processes should be driven by the frequent drumbeat of consumer demand rather than by the dated and infrequent drumbeat of classical scheduling. Therefore, strategic buffers must contain sufficient inventory to offer strategic processes new work as required by constantly changing consumer demand arriving upstream initially in relatively large process batches. Later, when a flow of replenishment is established, the inventories in strategic buffers can be lowered.

When legacy scheduling occurs less frequently than SC inventories are updated, the gating buffer must offer more choices of processing work than other buffers. BIFRS can then re-prioritize the release of work from the gating buffer to re-balance the entire SC at the drumbeat of the external ***and*** internal constraints.

Transfer batch sizes should be minimized everywhere until capacity is at risk. Process batch sizes should be maximized by scheduling, especially on the constraint process to avoid the high costs of changeovers and lost capacity. The following figure lists the capacity and throughput conflicts:

The BalancedFlow High Velocity SC

Capacity, Cost, and TT Relationships

To Increase Capacity:	**To Decrease TT:**
- Increase machine speed.	- Same.
- Reduce off-quality in/out.	- Same.
- Increase gross efficiency:	- Same:
- Increase operator efficiency.	- Same.
[redacted]	
- Increase process batch size.	- Same.
- Increase transfer batch size.	**- Decrease transfer batch size.**
- Decrease out-of-stock waits:	- Same:
- Increase buffer size.	**- Decrease buffer size.**
- Increase buffer refill speed.	- Same.
Only on the Internal Constraint	**On every process**

Increasing TT increases changeovers, decreases capacity, and increases costs. This is justified when faster TT (which generates additional units sold) plus reduced inventory expenses together exceed the additional changeover costs.

Figure 9

Figure 9 – Capacity and Throughput Conflicts

Buffer and batch size trade-offs must be evaluated globally to determine optimum buffer and batch levels. BF does this through Replenishment Optimization calculations.

14. The BalancedFlow Supply Chain THROUGHPUT Time Management Chart

The following chart shows the BF concept with the primary measurement of TT in DOS on the Y-axis. This chart is also the primary SC status chart for each family of items produced on a defined SC and identified as a production group code or PGC.

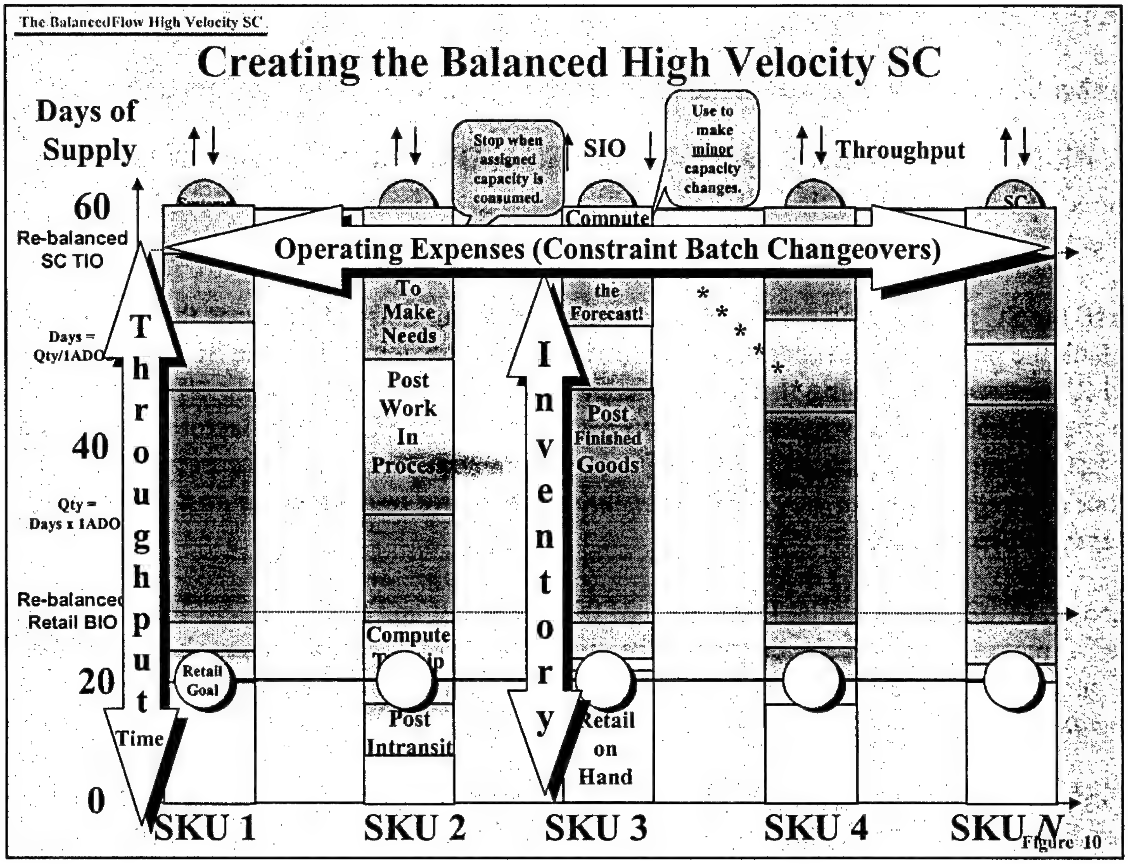

Figure 10 – The BalancedFlow Supply Chain Management Chart

This example SC family has 5 SKUs, a TT target of 60 TIO days for the SC, a TT target of 20 BIO days for retail stocks, and is currently balanced at about 55 DOS. The on-hand inventories converted to DOs are shown for each of the SC segments starting with retail on the bottom and ending with WIP on the top. The orange shows the shipping requirements and the SC shortage vs the SC goal. The manufacturing requirements are shown in green. BIFRS computes the shipping and manufacturing requirements as well as the manufacturing variances.

The large arrow on the left indicates TT in DOS is the primary operational measurement. The INV arrow is the same height as the TT arrow to indicate the one to one relationship between TT and INV. TT can only be reduced by removing INV, but OE in the form of batch changeover costs on the constraint, limit the amount of INV that can be removed.

The first step is to flow (ship) finished goods to keep the yellow bars that represent the target buffer's on-hand DOS equal to the round yellow targets that represent the target buffer's desired DOS. The next step is to assign sufficient manufacturing capacity on the constraint process to keep the top of the green bars on the green targets representing the TT of the complete SC. The third step is to assign the constraint process sufficient work (quantity and priority) to rebalance the SC from the constraint process forward each time inventory status can be updated. With the inventories balanced in DOS at all levels within

the SC, we can begin our fourth step of removing WIP, FG, and retail inventories to create a high-velocity SC.

Further details of the features of the chart are explained in Volume II of this document.

15. BIFRS Optimizes SC Balance, TT, Capacity, OE, and INV via the Constraint

The SC partners can use the BalancedFlow system to optimize all four of our SC objectives ***at the same time through the constraint.***

First, the SC partner who owns the target segment of our defined SC turns the key to unlock the power of BalancedFlow by flowing incoming demand up the SC through BIFRS instead of batching it. This begins the elimination of the bullwhip effect and, through BIFRS, quickly reaches the gating segment of the SC at manufacturing. Flowing demand rather than batching it up the SC dampens the demand curve for every strategic process owner along the way. ***This levels manufacturing requirements and minimizes manufacturing costs.***

Second, by using the available capacity of the constraint and the BalancedFlow TT chart, the SC partners can re-balance the SC frequently to eliminate stockouts at the end of the SC at the existing level of INV investment. ***This eliminates stockouts and maximizes revenue.***

Third, with sufficient balance in place and daily adjustments for demand forecast error based on actual daily demand, we can minimize TT and INV until changeover driven OEs in the form of setups on the constraint limit further improvements. ***This minimizes INV across the entire SC.***

Fourth, the same new SC science principles that the manufacturer learns while implementing BIFRS also transition directly to the world-class changeover team that is reducing setup time by at least 50 percent on the constraint. Each day of reduced setup time results in the gift of removing two days from INV, one from the constraint and one downstream of the constraint. This can be replicated many times over to eventually ***remove 50 to 90 percent of the INV and TT from the SC.***

As an alternative to INV and TT reductions, the reduced setup time can be enjoyed as lower OE and more SC capacity. In fact, it can be taken as a combination of either or both of these paired improvements.

This is why senior managers must manage the SC by managing the single internal constraint and production-floor managers must insure the constraint stays fixed in place and operating as expected. Following are some ways to optimize control over and use of the constraint.

15.1 Break the Constraint Only When More Capacity is Required

Often, production managers have the burning need to increase the capacity on a particular manufacturing process. They almost always limit their options because they phrase the

question in the wrong manner. The first question in this situation should be: "is this the real constraint to my goal of making more money now and in the future?" If it is not, leave it alone for there is much more important work to accomplish right now in identifying the constraint and fixing it in place.

The second question should be: "how do I maximize profitability now that I know what my constraint is?"

The correct advice is to not move immediately to "break" the constraint. If the SC does not have sufficient capacity to meet consumer demand, first subordinate all actions to the constraint. This simply means ***(1) optimize the constraint's gross efficiency and production hours (2) on the highest OCTANE SKUs, (3) that will turn into cash the fastest.***

When the need is stated in this manner, all kinds of help immediately becomes available for the manufacturing manager. The production line is responsible for # 1, sales and marketing are responsible for # 2, and BIFRS handles # 3. Once management realizes they have all these options for more profitability, it is no longer just a question of how to get the constraint process to run faster. In fact, this is a technical undertaking that does not even need to be addressed in most cases. Now, what are some of the actions that can be taken to manage the SC better through the constraint?

15.2 Minimize Setup Time and Costs on the Constraint Through World-class Teamwork

The number of changeovers on the constraint process determines SC capacity. The values for OCTANE depend on the SAHs on the constraint process. TT, OCTANE, quantities demanded of each SKU, and total constraint capacity together determine profitability. TT and SC capacity are a tradeoff only on the constraint and SAHs must be correct first on the constraint. Changeover costs on the constraint consist of the labor and materials required to conduct the changeovers, direct labor efficiency losses following the changeovers until operators are back to normal productivity, and the loss of sales from the lost production capacity during the changeover. ***It is an imperative to focus the first world-class teamwork project on reducing changeover time on the constraint.*** Normally, changeover times can be reduced 50 to 90 percent. Even a 10 percent reduction gives an immediate payback. It is common for this the payback to be realized before the first changeover implementation is completed and there is almost never a higher or easier payback than reducing changeover time on the constraint process.

15.3 Establish a Quality Inspection Point at the Internal Constraint's Buffer

Take every available action to keep the constraint producing first quality products. Producing quality work on the constraint is more important than producing quality work on any other process. Capacity lost on the constraint is lost forever. A second quality item wastes the constraint's time whether the non-conformance was brought into or created by the constraint. Establish an in-process quality audit or inspection station on the constraint's buffer to remove non-conforming parts. This does not damage throughput or capacity because this buffer must exist to protect order dates and capacity. Taking an

order out of sequence does minor damage compared to having to rework it on the constraint later on.

Reworking a second quality item on the constraint is the most costly operation in the entire SC. If an item is produced once and reworked once on the constraint, the probability is high that the item is still a second and two or more first quality items are lost totally from capacity due to these interruptions! Also, never use part of the constraint's capacity for rework unless no more first quality production is needed.

15.4 Cross-train First on the Constraint

Cross-train everyone first to the constraint, ***no matter where it is located.*** Cross-train next to the bottlenecks required to keep the constraint supplied. Sufficient skilled labor must be available to man the constraint first during normal hours and when additional production is required on overtime. Cross-train next to protect the constraint so it never runs out of first-quality input. This defies the traditional practice of cross training to the adjacent jobs or processes.

When more capacity is required, after all less costly actions are taken, only use overtime for constraint process workers and others if required to maintain the constraint's buffer.

15.5 Bypass the Constraint

Evaluate every possible way of taking work off the constraint even if the alternative appears to be very inefficient. The true profitability for exceeding the business plan is the sales price minus the inventory costs. Taking the smallest process batches off the constraint and producing them on another "inefficient" operation just may increase profitability significantly when the global impact on all objectives is considered.

Search for products that do not require processing on the constraint! Success in this effort can make a huge impact on the production floor and the bottom line because the OPERATIONAL EXPENSES will be close to zero. However, care must be taken to retain sufficient protective capacity on these non-constraints.

15.6 Consider a Toyota Type Production Line

Evaluate all possible manufacturing line configurations from the current mass production type line through the ultimate Toyota-type line evaluating impact on the goal through the four objectives – not just on the local operating expense objective.

16. Paired Production – the Strategy for Survival and Growth!

The premier strategy for basic survival and growth is "Paired Production" within the same SC. This works especially well when there are requirements for samples, mass customization, or extremely fast production. In fact, many manufacturers are already doing this to a limited extent, but it is even more important to do it as a strategy for radical improvement. Done on a very small scale, Paired Production is the way to open the future world of mass customization and fast-turn manufacturing with minimum risk

or cost – and a lot of learning has to take place for a traditional large batch manufacturer to make this change.

When increasing the velocity of a SC, a point may be reached at which smaller buffers and batches will generate changeover costs that exceed the benefits of increased throughput speed. In this case, a small high-velocity line may be the breakthrough needed. It may generate higher costs per item, but the net savings of taking the disruptions off of the larger low-cost line while meeting mandatory customer demand may be more than sufficient to justify the small, high-velocity line.

The larger line should be designed and located for the lowest possible manufacturing costs. The smaller line should be designed and located for the highest possible speed to the consumer.

This strategy works at many different levels. For example, the same items could be produced on paired production lines within the same plant or part of the line could be domestic and part offshore to enjoy lower labor costs. In fact, retailers could drive paired production themselves by acquiring the same items from different manufacturers.

This strategy also works very well to reverse the rigidity of production on high-speed machines that require long setup times. Generally these newer high production machines were installed to increase operator efficiency. This is ideal for mass production of large quantities of the same item, but very costly for short production runs of different items that require long setup times. Normally the older machines are still available and operators can still operate them. The outcome is amazing when smaller requirements are off-loaded onto the less "efficient" and older machines. The older machines produce less, but also require much shorter changeovers, thereby reducing changeover costs (OE) and increasing capacity on the "high efficiency" machines.

This strategy should always be one of the first alternatives considered when more capacity is needed. It is usually superior to purchasing another mass production machine. In fact, in the pure application of Lean/Agile Manufacturing, totally dismantling and disposing of the high capacity machine would be the first action considered and often the first action taken.

17. The BalanceFlow System addresses All Major Core Supply Chain Problems

Root causes and core problems are the policies or logistical rules that either create artificial constraints or limit the performance of the natural internal constraint. Root causes and core problems must be properly identified so actions and resources can be concentrated here rather than trying to fix the many symptoms of problems exhibited by traditional dysfunctional SCs. Our research found that most SCs have the same basic root cause and core problems. The BF system is designed to eliminate the following common traditional root cause and core SC demand generating and order fulfillment problems:

(1) Consumer demand is generated through marketing and sales with nonexistent or false measures of true profitability at the product level.

(2) Consumer demand is aggregated and presented by the retailer in an unpredictable manner.

(3) Consumer demand occurs at least daily, but responses up the SC occur days, weeks, or months later.

(4) Manufacturing decisions are made without total asset visibility down the entire SC.

(5) Local optimization (demands for efficiency) rewards the making of items that are in long supply rather than items that will sell next.

There well may be other core or root-cause problems and, if so, they must be identified and addressed. However the five listed above are the ones common to most SCs and the BF system provides the efficient methodology for their resolution as the means of optimizing the SC in relation to our stated goal of maximum revenue at minimum total cost.

18. Expected BF Benefits

How much improvement can we expect from the implementation of BF? A Deloitte & Touche study reports that companies that link their customer resource management and supply chain management activities to create "loyalty networks" can be much more profitable. The report, based on interviews with 850 manufacturing executives in 35 countries, found that companies that link the two applications are almost 19% more profitable than companies that emphasize only customer relationship management and 54% more profitable than companies that focus on only supply chain management. They are also 70% more profitable than companies that work on neither area. BF links the most important parts of these two systems with additional critical capabilities.

The following figure shows the primary areas and levels of benefits that can be realized through BalancedFlow BIFRS scheduling and fast-turn manufacturing:

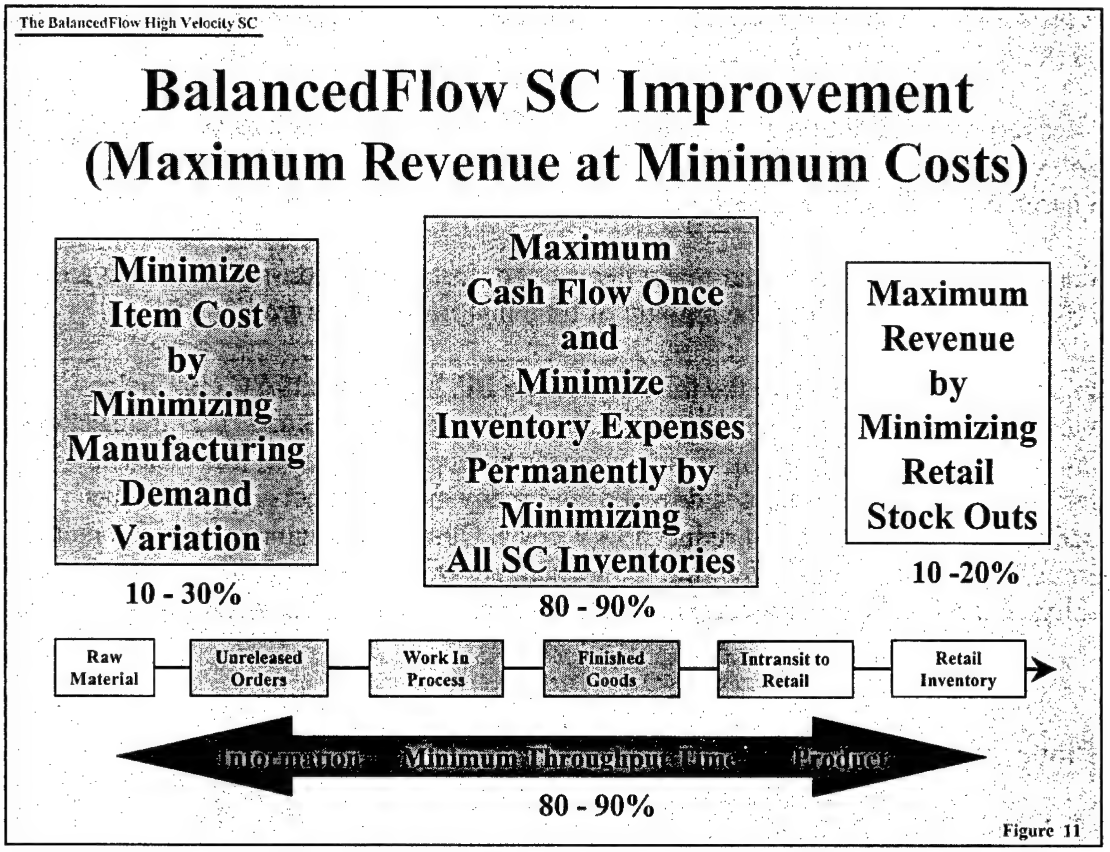

Figure 11 – BF Improvement Potential

The goal of achieving maximum revenue at minimum cost is realized by maximizing TT, which can normally be improved by 80 to 90 percent. This is accomplished by exchanging information for product on a very frequent basis. Stockouts are improved by 10 to 20 percent by achieving an inventory balance (in days-of-supply) supported by extremely fast replenishment reaction times. Inventory investments are reduced 80 to 90 percent by reducing buffers and transfer batch sizes. Item costs are reduced 10 to 30 percent by eliminating expediting, leveling demand, reducing time spent on repairs and rework and by eliminating rework.

The implementation of BIFRS alone will result in the stock out improvements and approximately half of the inventory and manufacturing cost improvements shown above. Fast turn manufacturing is required to achieve the second half of the INV and manufacturing OE improvements. The TT management chart provides the focus for passing the improvement efforts back and forth between SC optimization and production line optimization.

BF generates a secondary level of benefits. The most important one at this level is that the concepts and management practices required for fast-turn manufacturing are exactly the same as those required for a lean SC. Implementation of a BF lean SC facilitates the implementation of Lean Manufacturing. Implementing BIFRS first is a fast, low risk, and

low cost way to introduce management personnel to SC science through mature examples found in the Theory of Constraints and Lean Enterprises.

Another secondary benefit is that the manufacturer can use the balanced SC to take advantage of other high-profit opportunities or to fill a shortfall in manufacturing demand with items that will sell the fastest.

A third benefit at this level is that many items once classified as non-replenishable are now replenishable because of the amount of time that BF removes from the SC.

There are numerous benefits at the third level. The BF, high velocity SC eliminates replenishment processes and the associated time, inventories, and costs. EDI transactions are no longer required. Changing customer needs are met much faster, less obsolete inventory exists when a product is dropped, and many more product choices can be offered for increased revenue at reduced INV costs. Other manufacturing benefits include minimizing the costs of quality, minimizing changeover requirements, increasing capacity, minimizing capital investments, and increasing forecast accuracy.

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20. Glossary

1ADOS	One average annualized calendar day of supply computed by dividing the forecasted annual demand by 365 days. Used to determine long term contracting and production requirements.
1RDOS	One average weekly retail calendar day of supply computed by dividing the forecasted weekly demand just beyond retail's replenishment wait time (RWT) by 7 days. Used to determine ordering or shipping requirements to maintain the retail buffer at a target level to support short-term forecasted demand requirements during the week immediately following the retailer's replenishment wait time.
B	Buffer. Inventory waiting for processing. Pairs of processes and their supporting buffers constitute supply chain segments.
Bd	Distribution buffers. Strategic distribution buffers support strategic distribution or shipping decision-making processes.
Bek	External constraint buffer. Strategic buffers that support the supply chain's strategic external constraint processes of consumer demand. Normally thought of as the buffer of retail inventory, but is the buffer next to any consumer.
BF	BalancedFlow. A supply chain that is first balanced in days of supply and then shortened in time through high-velocity order and product flow.
Bg	Gating buffers. Strategic gating buffers support strategic gating processes.
Bi	Non-strategic buffers that support non-strategic processes.
BIFRS	Balanced Inventory Flow Replenishment System. The supply chain scheduling software component of the BalancedFlow system.
Bik	Internal constraint buffers. Strategic internal constraint buffers support the supply chain's strategic internal constraints.
BIO	Basic Inventory Objective. The supply chain's inventory objective or target stockage requirement expressed in quantity or days of supply without consideration of inventory protection for promotional or seasonal demand variations.
Bs	Scheduling buffer. Strategic buffer of manufacturing orders or requirements that supports the strategic process of scheduling.
CAR	Clemson Apparel Research.
CWT	Customer wait time. The time the downstream process owner has to wait for order fulfillment once a replenishment order is passed upstream. More commonly called replenishment lead time or RLT.
DBR	Drum Buffer Rope. The Theory of Constraint's (TOC's) replenishment concept consisting of the customer's drumbeat of demand, a buffer of inventory that ensures immediate demand fulfillment and a rope connected to the upstream gating process. A signal is sent by the rope for new work in a manner that maintains the optimum buffer level based on real-time consumer demand.
DOS	Days of supply. The number of calendar days that a given quantity of inventory is expected to last while supporting a forecasted consumer demand.
FG	Finished Goods. Completed work-in-process (WIP) residing in a buffer at the manufacturing facility waiting distribution or shipping decisions.
INV	Inventory. A TOC parameter consisting of all the money invested in inventory which will be consumed once all the money invested in operating expenses (OE) is used to convert the inventory into throughput (T).
Lean	The Toyota concept of operating a production line or supply chain with minimum inventory.
Non-Strategic	Identifies the many non-strategic buffers, processes, and segments of the supply chain. These process owners should have no choices of what to work next. Their buffers should be reduced to minimum transfer batch quantities in order to minimize throughput time (TT) for the entire supply chain.
Octane	An analogy to the different octane ratings for gasoline that are a measurement of combustion temperature and power. Within a manufacturing plant Octane is the relative contribution to

	profit of each SKU based on the total operating expense (OE) of the plant and the SKU's contribution to throughput (T).
OE	Operating Expense. A TOC parameter consisting of all the money paid to convert money invested in inventory (INV) into throughput (T).
P	Process. Value-added physical transformation or movement of orders up or inventory down the supply chain. Pairs of processes and their supporting buffers constitute supply chain segments.
PBT	Production Backlog Time. The number of days the next customer order must wait in the scheduling buffer (Bs) before it can be released to manufacturing through scheduling (Ps).
Pd	Strategic process that determines distribution or shipping quantities and priorities.
Pek	Strategic external constraint process of consumer demand. Generates the primary drumbeat that should drive every upstream process in the supply chain beginning with Pik.
Pg	Strategic gating process that must to which new production orders must be released in a manner to maintain the target buffer level for the internal constraint (Pik).
PGC	Process Group Code. An identifier that is used to group families of individual items that have minimum changeover requirements on the constraint process (Pik).
Pi	Non-strategic processes.
Pik	Strategic internal constraint process (the largest bottleneck in relationship to the supply chain's goal) normally found within manufacturing. Should be the primary target of scheduling and should be operating at the same pace as Pek adjusted for seasonal or promotional demand and inventory residing between Pik and Pek.
PLT	Production Lead-time. The standard number of days required to produce an item once the order is released to manufacturing. Within BIFRS this does not include the variable amount of production backlog time (PBT) an order has to wait in the scheduling buffer to reach its turn for release to production because this wait time is eliminated. However, many manufacturers have highly variable PLTs because they release all orders to manufacturing and have no ability to control and monitor production backlogs separately from manufacturing lead-time. Total manufacturing lead-time = PBT + PLT.
Ps	Strategic scheduling process. This can refer to the legacy scheduling process or the B IFRS scheduling process.
RLT	Replenishment lead-time. The time the downstream process owner has to wait for order fulfillment once a replenishment order is passed upstream. Also called customer wait time or CWT.
SAHs	Standard allowed hours. The standard allowed time in hours for a process or task. Can refer to the time required for a single SKU on the task or process or a batch of SKUs on the task or process. Item costing, production operator pay, and production scheduling are all based on these standard times.
SAMs	Standard allowed minutes. The standard allowed time in minutes for a process or task. Can refer to the time required for a single SKU on the task or process or a batch of SKUs on the task or process. Item costing, production operator pay, and production scheduling are all based on these standard times.
SC	Supply chain. Refers to a complete supply chain as defined by SKUs, processes, buffers, segments, sections, batches, and is uniquely defined by the one common internal constraint process (Pik).
SIO	Seasonal inventory objective. The days or quantity of inventory required by week when the demand is seasonal or promotional for the manufacturing line to operate at a level rate every week of the year. This is inventory required above the basic inventory objective (BIO) to avoid penetration of the BIO during the periods of high seasonal or promotional demand.
Six Sigma	The process improvement methodology used very effectively by General Electric and other manufacturers.
SKU	Stock keeping unit. Normally a retail number used to uniquely identify a basic item. Used by BIFRS across the entire supply chain to identify basic items within each supply chain section. The SKU for a single item may change from supply chain section to section.
Strategic	Identifies the limited supply chain processes, buffers, and segments that have sufficient intentional inventory to permit the process owners to have choices of different SKUs to

	process next. BIFRS determines the priority and quantity of work for each strategic process owner to rebalance the entire supply chain based on the inventory status of the supply chain from the position of each strategic process owner to the end of the defined supply chain.
T	Throughput. The primary TOC parameter consisting of the new money generated by converting inventory into sales by the application of operating expenses (OE). BalancedFlow uses TP rather than T.
TAV	Total asset visibility. The state of capturing inventory levels from all segments of the supply chain in a manner that permits high level visibility and informed replenishment decisions.
TB	Target buffer. Any strategic buffer of inventory located at the end of a supply chain section.
TIO	Total inventory objective. The total inventory target for the supply chain for a given week computed by summing the basic inventory objective (BIO) and the seasonal inventory objective (SIO) for the given week.
TM	Throughput money. A CAR BalancedFlow acronym used to break the TOC definition of throughput (T) into its two elements of throughput money and throughput time.
TOC	Theory of Constraints. Introduced by Goldratt in his book The Goal in 1986.
TP	Throughput. A BalancedFlow acronym used instead of the TOC acronym "T" for throughput.
TT	Throughput time. A BalancedFlow acronym used to break the TOC definition of throughput (T) into its two elements of throughput money and throughput time. TT is the primary metric and driving focus of the BalancedFlow system.
WIP	Work in process. Production orders released to the manufacturing floor by scheduling and not yet transferred to Finished Goods. Encompasses any number of supply chain processes and buffers.

BALANCED INVENTORY FLOW REPLENISHMENT SYSTEM (BIFRS)

Part II
BalancedFlow Implementation Procedures

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Implementation Procedures

1. Implementation Procedures Summary

The SC partners attend a one-day seminar and workshop in which they learn the BalancedFlow (BF) concepts and terminology presented in Part I and develop their pilot SC consisting of one family of products. In the workshop they define their pilot SC's components, establish its operating parameters, and set its goals, objectives, and performance metrics. CAR enters the operating parameters into BIFRS and provides Excel formats for the partners to fill with recurring forecasts and inventory status from legacy systems. Normally, the partners can populate the forecast and inventory status formats the same day permitting an initial BIFRS run and evaluation by the end of the workshop. This initial BIFRS run demonstrates the power and potential of BIFRS on actual data from the partner's SC and is the basis for deciding if the installation should proceed.

CAR then customizes the BIFRS software engine as required and coordinates with each SC partner to acquire all parameters and recurring inventory status and forecasts electronically and efficiently. CAR tests and modifies the software until it is stable and operational responsibility can be transferred to the designated partner. CAR can load the software on the manufacturer's own computer system or maintain it on the CAR server and provide access through the Internet.

The partners run BIFRS in a test mode to identify further programming refinements and to learn the system's requirements and capabilities. CAR makes programming changes and assists with training as required during this period. Once the partners determine that training and testing are complete, they use BIFRS to drive the pilot SC. Once the pilot SC is running routinely, additional families and SCs are activated.

The implementation should begin with the manufacturing segment that contains the manufacturing constraint. In addition, it is usually best for the manufacturer to master the concepts and software internally before extending BF to the first external customer or supplier. The extension to a downstream customer is then a simple extension of the finished goods warehouse. The extension to an upstream supplier is slightly more complex because of the requirement to tie the rope from the constraint process to the new upstream gating process.

There are two technical requirements for the application of BIFRS. Inventories must be accessible through automation (assuming the number of SKUs is too large for manual data input) and there must be a target of buffer inventory such as retail stocks, distribution center stocks, finished goods, or assemblies at the end of the defined SC. While BIFRS is a replenishment scheduling system, it also launches production orders for non-stocked or non-replenishable items.

The implementation may use different periods of BF cycle time as appropriate. The base case and the example discussed in this document both use weekly legacy scheduling, daily BIFRS scheduling, days-of-supply, days of process lead-time, and standard allowed hours of value-added production time. BIFRS should be run at least as often as legacy scheduling is conducted within manufacturing. The frequency at which BIFRS is run is called the BIFRS cycle. The more frequently it is run, the lower the inventories and the faster the throughput time. For example, the BIFRS cycle may be daily to drive the manufacturing constraint and distribution, but weekly to generate new manufacturing requirements for legacy scheduling. The key is that BIFRS should be run as frequently as legacy system data is updated to generate action, but only in accordance with established operational parameters. This is how BIFRS begins to reduce the tails of the distribution curves and move the averages in the proper directions. It can be run in real-time if new orders and inventory transactions are posted in real-time to the supporting legacy system.

Each SC partner can enable their up and down stream SC partners to enjoy significant improvements in one or more of the objective areas provided the amount of business is at least 10 percent of the partner's total business. Otherwise, some type of automated auction or low-bid replenishment probably remains the best business approach.

Benefits accrue and ***multiply*** in steps within the SC as functional boundaries are breached, as the external constraints' buffers are balanced to eliminate stockouts, as inventories are lowered for high velocity throughput, as manufacturing requirements are stabilized, and as the process is replicated for upstream sub-assembly or raw material manufacturing. Benefits multiple even faster as additional items or families are added to the initial SC and as additional SCs are activated.

1.1 Selecting the Supply Chain Team Members

The ultimate BalancedFlow SC team consists primarily of the individuals responsible for replenishment at the end of the SC and all of the individuals who make distribution or scheduling decisions for each of the major segments of the SC through initial raw materials manufacturing. Manufacturing supervisors of the SC segments that contain the manufacturing constraints should also be primary members because the output of BIFRS will directly impact their areas of responsibility.

Supporting members include the information systems people who must extract and provide the data from each SC segment and any other individuals deemed necessary to participate in the effort.

If any of the organizations are doing any type of fast-turn manufacturing, or are considering this, then leaders from those efforts should also be included as primary or supporting team members. This will greatly facilitate both the BIFRS scheduling and fast-turn manufacturing efforts.

In addition, senior managers from each organization must be totally committed to the effort and must fully support it within their organizations. It is vital that this support

includes the supervisors of the primary team members. Specific and challenging guidance should be given to the team in the form of targets for each of the four BIFRS objectives.

Once the primary team members establish the supply chains, operating parameters, and detailed objectives, they must present them to a joint meeting of the senior leadership of each organization for approval.

Normally the effort will begin within manufacturing where the new concepts can be mastered before extending them downstream to customers and upstream to suppliers. However, care must be taken to build the complete team as quickly and as strongly as possible. When functioning properly, the team can be compared to a relay team.

If the baton is not handed off as quickly as possible in every leg of the race, the team will not have the fastest possible time. The baton represents replenishment and manufacturing orders as well as product moving down the SC.

If the quality of the handoff is not high, the team will not have the fastest possible time. If there is any wasted effort anywhere during the race, the team will not have the fastest possible time. If anyone tries to carry anything extra or if anyone loses focus on the objective, the team will not have the fastest time. The anchorman who places the baton across the finish line first claims the victory for the entire team. When all the team members of the SC feel just a little of the emotional thrill that all the members of the winning relay team feel, we will have a winning SC.

By the way – our team does not have to actually have the fastest possible time – just a time that is faster than that of the next team!

The focus of our team is THROUGHPUT, all non value added effort must be eliminated, and the daily display of the status of the BF SC is the motivational rallying point for our entire SC team.

1.2. Selecting the First Family of Items and the First Supply Chain

The first family of items should be a long-running family (in contrast to a short-life or high fashion item) that can be used to establish the operating system and fully train each strategic process owner. The initial SC should consist of two full SC segments and four inventory segments as defined in Section 3. Implementation should normally begin within manufacturing, but be extended quickly to the downstream SC partner. This gets to the "low hanging fruit" of minimized retail stock outs (the balance) and sets up the links for minimized inventories (the high velocity TT). Sufficient balance can normally be achieved without increasing overall inventories. In fact, just acquiring total asset visibility and displaying it on the TT chart normally permits an immediate 25 to 50 percent inventory reduction for the defined SC segments. Once sufficient balance is reached to protect the first family of items against stockouts, inventories can be reduced further to decrease TT, the SC can be extended upstream to assemblies or raw materials, and additional families (PGCs) can be easily added to the SC. This measured initial start

permits the completion of the basic learning cycle based on activating only one family of items on BIFRS.

1.3. Expanding BIFRS to become the Planning and Scheduling Tool

The ultimate BF rollout objective is to add all families of items to the pilot SC, extend the pilot SC as far as possible in both directions, and activate other SCs. After the first item is functioning properly, additional items are added, the SC is expanded, and the initial SC is replicated. SC performance (in relation to the goal) multiplies with each of these steps. However, the SC objective of level manufacturing can only be approached when sufficient items are on BIFRS to significantly level the total production line. Experience has shown that approximately 10 percent of a production line on BIFRS is sufficient to make a significant contribution to leveling the entire production line. This small percentage on BIFRS, coupled with total asset visibility across the SC, gives the manufacturer risk-free flexibility of pulling-in or pushing-out BIFRS work to accommodate new opportunities for non-BIFRS items or of filling open production capacity with BIFRS items that are in shortest supply.

In the beginning BIFRS' time horizon is much shorter than that of legacy scheduling because it is designed to fill the void of ***what to do next*** based on the current SC situation to re-balance the SC from each ***strategic process*** forward through the target buffer. Under legacy scheduling, each process operator does next what was scheduled days or weeks in the past as modified by expediting. (And the work scheduled days or weeks in the past was even further removed from the point of consumption by large batches of infrequent replenishment orders.) Under the consumer drumbeat of balanced high velocity flow, each strategic process operator works next on what will turn into the most profit the fastest. Expediting is controlled by BIFRS and takes place only within the strategic buffers based on well-defined business rules. Expediting is eliminated from the manufacturing floor.

When the majority of items made on one production line are activated, BIFRS begins the transition from a "what to do right now" tool to a comprehensive constraints-based planning and scheduling tool. BIFRS can not replace legacy scheduling until all of the manufacturer's production ***and raw materials*** are on BIFRS. Therefore, for some time legacy planning and scheduling systems continue to identify all capacity requirements, generate raw-material orders, and workload non-BIFRS items. During this time BIFRS simply determines what each strategic SC process segment owner should do ***immediately*** to optimize SC performance. ***BIFRS provides the real-time consumer-driven drumbeat of consumer demand that is lacking in all classical and lean scheduling systems.***

When BIFRS is extended to all items including raw material suppliers, it can replace legacy scheduling and multiply profitability even more by extending its direct benefits to more segments of the SC and eliminating the operating and inventory expenses associated with legacy scheduling. The BIFRS annual forecast can then drive the one-year planning cycle for the creation of capacity up the entire SC. All buffers except those in the few strategic SC segments can be eliminated to optimize throughput. The retained buffers at the strategic segments are sufficient to protect SC capacity and individual order

due dates from demand and replenishment variations. Non-replenishable items become replenishable based on the decreased TT. When this point is approached, the SC partners begin to realize they have crafted an insurmountable competitive advantage.

2. Defining the Supply Chain Segments

BalancedFlow defines the supply chain in three different levels of detail. The highest level shows the core functions and major partners. The middle or second level is the focus of BIFRS and shows the major segments consisting of processes and buffers. The lowest level of detail should be the focus of a ***separate*** BalancedFlow effort to reduce changeover times and this level goes to the individual tasks within the processes. To minimize confusion when the SC partners begin to flow their SC, let's first describe this most detailed level of effort and describe how it compliments BIFRS under the BalancedFlow concept.

2.1 The World-class Changeover Team Focuses at the Detailed Task Level

This third level of detail should be the focus of a separate BalancedFlow effort on the production line that compliments the implementation of BIFRS. A world-class team should be fixing the natural constraint in place and reducing its changeover times by 50 to 90 percent. This takes 2 to 6 months to accomplish as does the implementation of BIFRS. BIFRS alone minimizes stockouts and removes about half of the time and inventory from the SC before it hits the limitation of batch sizes on the constraint. BIFRS is scheduling the constraint so reducing batch sizes on the constraint is vital to achieving the other half of the total time and inventory improvements. Lets take the time to describe this lowest level of detail before we return to BIFRS scheduling.

2.1.1 Promoting and Fixing the Natural Constraint in Place

Let's assume our current largest bottleneck in manufacturing is attaching collars on shirts. However, setting sleeves is our natural constraint and currently our second largest bottleneck. We need to promote it so it becomes the largest bottleneck and we need to keep it as the largest bottleneck. To promote the natural constraint, we have to determine what needs to be done to break the current constraint. Lets assume there are no obvious temporary problems such as unproductive workers or lack of work so we have to tackle the long-established collar-making segment of the SC. Lets begin by having our changeover team define and flow the steps in the process.

At collar attachment bundles of collars and shirt bodies for 50 shirts are transfer batches that are processed (moved) to a sewing station. They sit as buffers until the operator conducts the next task of acquiring and opening them. The two bundles are then slowly decreasing buffers as the operator acquires, sews and disposes of each individual part. The new bundle of sewn parts is now a slowly increasing buffer of completed parts. In this short portion of the entire SC, the sewing step (needle going through the fabric) is the only value-added task. All other tasks are non-value-added waits or processes. Some of these tasks may be necessary conditions (such as positioning the fabric on the sewing machine), but the customer has no concern as to how these tasks are conducted because they have no impact on the form, fit, or function of the final product. In addition, the

customer has not specifically requested them and regulations or laws do not require them. Their costs should be eliminated or minimized in every possible way.

The changeover team should be focusing on the changes required to minimize the setup time when changeovers occur at attaching collars. Each time that the changeover setup costs can be cut in half, the bundle of 50 can be cut in half and both WIP and TT will be almost cut in half. Therefore, the changeover team must work on the individual tasks now required for the setup and eliminate or reduce as many as possible. Success in reducing changeover requirements at this process promotes the natural constraint of sleeve setting to become the largest bottleneck.

2.1.2 Minimizing Changeover Time on the Natural Constraint

Next the world-class changeover team repeats the process on the natural constraint. However, the difference here is that we will not break this constraint – we will manage the entire SC by it! Once changeover time is cut by 50 to 90 percent here, we can take this gift in a number of different ways. We could reduce the headcount and operating expenses, but that would end all of our BF efforts quickly. We can reduce PLT by the amount of setup time that is removed and we can also take the same amount of time and inventory out further downstream to optimize TT. We can instead do fewer changeovers and surge a few items for a short period of time to give us a burst of additional capacity. (However, we can not do this for too long or we must increase downstream inventories to protect against stockout.)

There are a number of other actions that our team can undertake in addition to reducing changeover times that will further reduce TT. One of the best is paired production. This occurs when the smallest production batches are placed on small, but fast-turn manufacturing lines and this is normally done using older, manual equipment. This optimizes response time to the customer, lets us fill in low demand items quickly without carrying inventory, gives us sample-making capability, and makes the large production line more productive and profitable. In addition, this is one of the very best ways to begin to practice fast-turn manufacturing with minimum risk and cost. It also opens the world of mass customization.

Lets now return to the level of focus for BIFRS scheduling.

2.2 BIFRS Scheduling Focuses at the Strategic Supply Chain Segment Level

The partners flow and define the individual segments of their supply chain to identify and document their strategic processes through which their defined SKUs flow. At this level, segments clearly follow a pattern of alternating buffers and processes. Following is a typical SC flow for a SC that is internal to manufacturing. It begins with raw materials and ends with finished goods. The strategic processes and buffers are the target buffer of finished goods, the internal constraint, and the gating process of cutting:

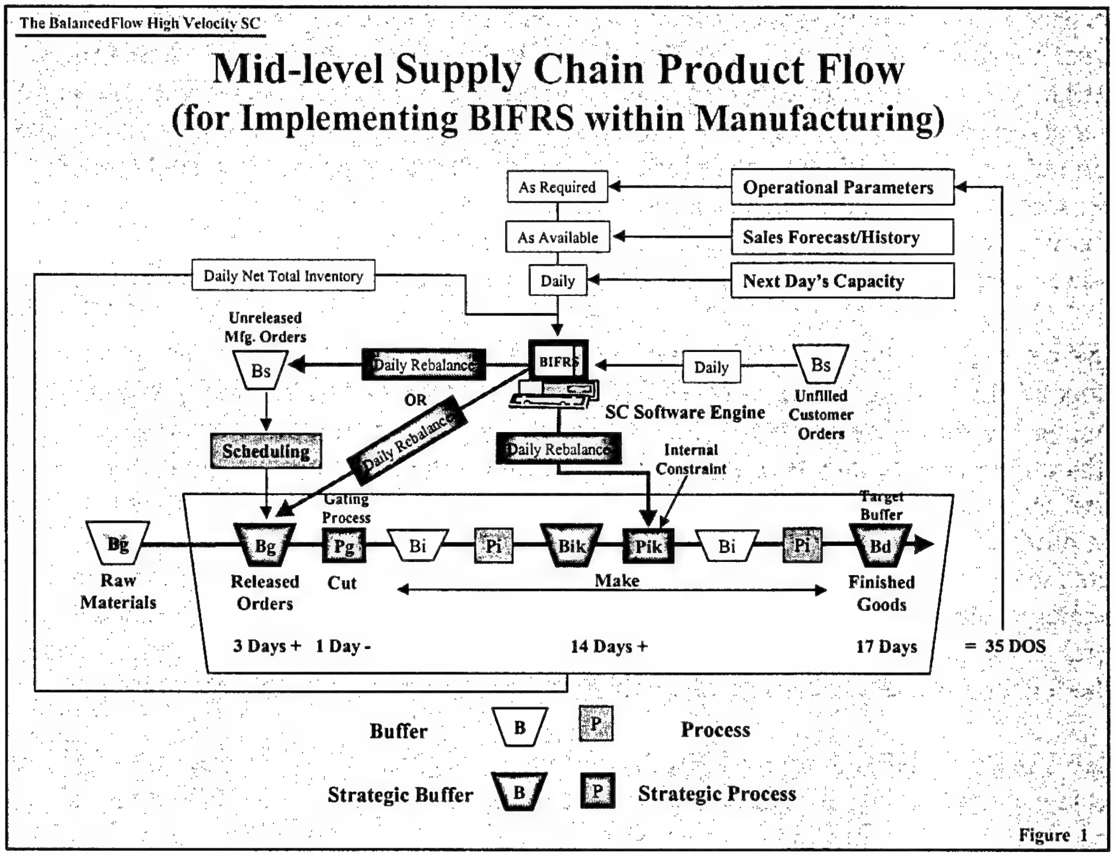

Figure 1 – BIFRS-Level Strategic Segment Flow

Processes modify, add value, or transfer the items to the next buffers. The trapezoids represent buffers and the rectangles represent processes. The yellow background color is the same color as the SC buffer segments to indicate that there is actually only ***one*** buffer and it extends the complete length of the SC. The key to optimizing the supply chain is to optimize the location and size of individual buffers, the flow of replenishment batches down the entire SC, and the flow of process batches across each process.

3. Defining and Grouping SC Items

3.1 Defining the Items

The partners begin to define the SC by selecting the first group of items that are made on the same manufacturing line and are included in the target buffer at the end of the defined SC. At retail these individual items are normally called stock keeping units (SKUs) and are assigned unique names and numbers. For standardization, BIFRS uses "SKU" and an associated part number to identify all items at any SC segment, but the assigned identities can change as the items move down the SC.

3.2 Defining the Production Line and BIFRS Inventory Input Segments

Since BIFRS is consumer-driven constraints-based scheduling, it only schedules the SC's internal constraint process and, if applicable, the distribution and gating processes (the constraint can be the gating process). Therefore, the SC is defined to begin with the target buffer at the end of the SC and to extend upstream to a gating buffer. The production line portion of the SC can all be in one physical location with all segments adjacent to each other, spread across a large plant, or spread across different plants anywhere in the world. The key is that the internal constraint does not move about frequently because it is the source of capacity hours promised to BIFRS items during the next BIFRS cycle.

All SKUs made on the same defined production line are assigned the same production line code (PLC). More specifically, all SKUs that cross the same constraint process belong to and define a particular PLC. The segments of the production line are just a continuation of the segments of the defined SC. Like the SC, the production line is defined in terms of the constraint. All SKUs that have the same constraint are on the same production line. In addition each of the defined SKUs (or their sub-assemblies) enters the defined SC through the same gating segment(s) (in one form or another) and ultimately resides in the "target" buffers of the terminal segment. However, there are several different ways to set up constraints-based scheduling within the defined SC based on the location of the constraint and availability of segmented on-hand inventory data.

Figure 1 in Part I defined high-level order fulfillment segments and lower level individual process segments of our BF SC. We now need to introduce the grouping of individual processes and buffers in a manner that permits the proper collection of inventory data. We call these SC Segment Groups and they actually fall between the high level segments and the process level segments defined earlier. In addition, these Segment Groups split individual process segments as shown below:

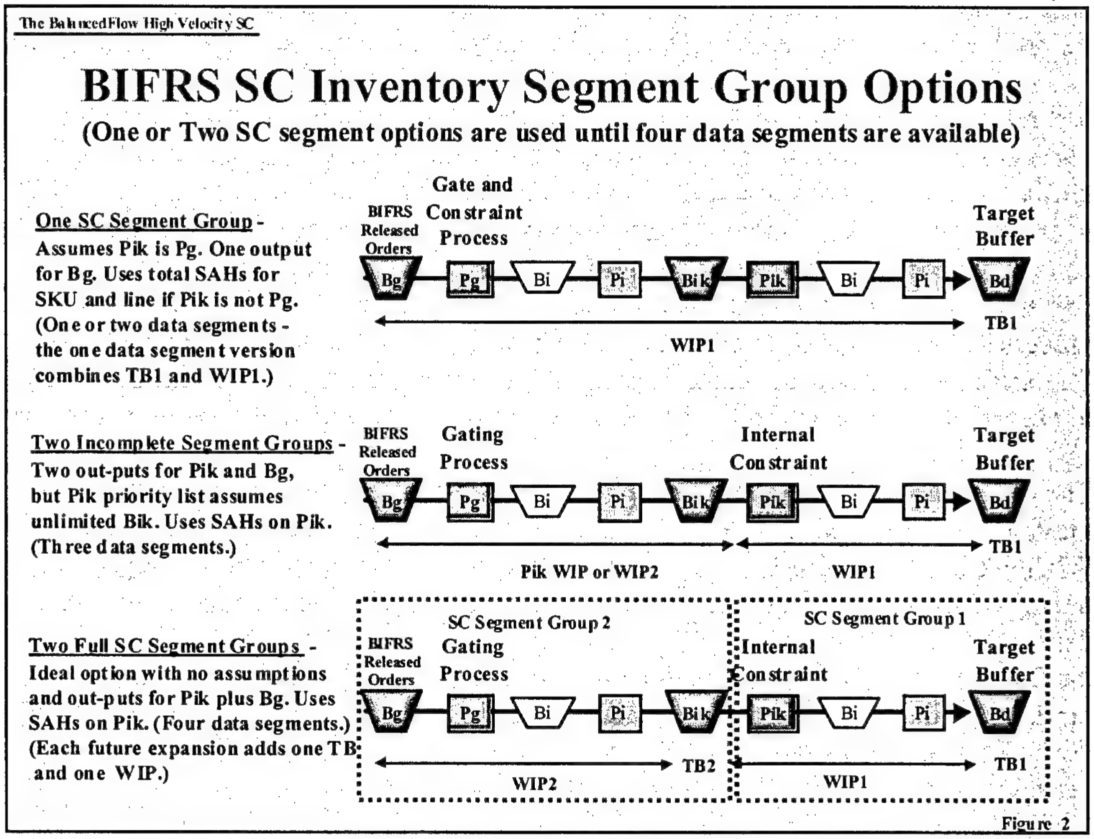

Figure 2 - BIFRS SC Basic On-hand Inventory Segments

The one-segment group is the simplest to schedule and can be an initial starting alternative. BIFRS only generates new work for the gating process of this SC because the constraint is also the gating process. There are only two sets of inventory-input data; the target buffer and the total WIP.

The two full segment group with four data segments is the preferred data input model. Here BIFRS accurately generates new work for both the gating process and the constraint process. This SC actually consists of two joined two-data SC segments with four total sets of inventory-TB1, WIP1, TB2, and WIP2. Both SC segments are driven by the promised capacity on the constraint.

There are three alternative ways of setting up BIFRS scheduling to meet special situations in lieu of the preferred two SC segment groups just discussed.

1) A one-data, one SC segment group can be used when it is not possible to obtain a further breakdown of data. In this case BIFRS can only generate new work for the gating process to re-balance the entire defined SC. However, this is the single most important output of BIFRS so it is a clear improvement over conventional scheduling. Since there is no defined constraint, the SAHs must be for the total item and the capacity for the BIFRS cycle must include time for every production operation. This option permits the removal of inventory from within the SC and from downstream

buffers once sufficient balance is achieved. However, this should only be a temporary fix until the constraint can be isolated and adequate data collection can be established.

2) A three-data, two SC group segment can be used when data is not available in four segments or the constraint process is so close in time to the gating process or target buffer that the precision of a four-data segment SC is not justified. In this case BIFRS generates new work for the gating process and a priority listing of work for the constraint process. However, BIFRS does not know what is available in the constraint's buffer, so it assumes unlimited work is available. Thus, the constraint process owner may have to skip some high priority work and move on down the list. The three sets of inventory-input data are the target buffer, the WIP on the constraint to the target buffer, and the WIP on the gating process through the constraint's buffer.

3) The two-data segment, one SC group segment can be used when the constraint is moving about too fast for it to be confined to one segment of the manufacturing SC. When we can not define the constraint, we can assume the constraint is the gating operation and only generate new production requirements to rebalance the total defined SC. In this situation, we now use the SAHs for the complete SKU (rather than the SAHs for the constraint process) and the total promised hours for the entire production line (rather than the promised hours for the constraint) for the next BIFRS cycle. This is a very acceptable approximation of pure constraints-based scheduling because it still achieves all the benefits of a balanced SC and some of the benefits of a high velocity SC. However, the scheduler **must** work closely with the floor supervisor to hold released work in a buffer at the beginning of the production line and flow it into the line at the rate that the line can sustain without starvation or increased inventories. The amount of work on hold must be considered manually when production line hours are promised to BIFRS items for the next BIFRS cycle. The hours promised have to be adjusted according to the amount of work on hold. This should be an interim approach to complete constraints-based scheduling while the production line constraint is being identified and stabilized.

There is one other consideration in tying BIFRS to the constraint. If the capacities of the largest bottlenecks are nearly equal, one can be selected arbitrarily and used for BIFRS. If one of these happens to be the gating process, it should be used to make scheduling even easier.

3.3 Defining the Item Groups

Each family of individual items made on a single production line can ***optionally*** be assigned to a unique BIFRS production group code (PGC) to facilitate computations and communications in the following four ways:

(1) The PGC is primarily associated with the SC constraint process in manufacturing at which the item identities originate. Items are grouped together for production because their manufacturing attributes are so similar that they can be produced with minimal or no changeover requirements on the constraint. An example is a single style shirt

(PGC) in multiple sizes that each has the same SAHs and essentially no changeovers are required between sizes. Each different sized shirt has its own SKU.

(2) The manufacturing process similarity for the PGC family may carry through to wholesale item management and marketing so the initial forecast can be at the PGC level for greater forecast accuracy than at the item level. If the concept of a PGC applies at manufacturing, capacity is reserved for the PGC requirement based on the PGC-level forecast and raw materials can then be converted to specific items at the absolute last minute based on a much shorter forecast period and total asset visibility. BIFRS actually runs at the PLC level so PGC production capacities are summed to obtain total capacity promised or committed to BIFRS-scheduled items on a single production line.

(3) The third use of the PGC is that it enables a more efficient way of loading common attributes into BIFRS rather than having to load SKU attributes for each individual SKU.

(4) Finally, the SC can be visualized and managed PGC by PGC as an alternative to only displaying all PLC items grouped together at the same time.

3.4 Defining Allocation Rules for Complex Supply Chains

Multiple production lines can produce the same item and the same item from multiple production lines can be mixed in downstream SC segments as fungible goods. Both situations require the use of replenishment algorithms that assign production requirements by defined rules. The general algorithm is the "paired production" algorithm that first assigns the SKUs with the smallest 1ADOSs to the manufacturer with the smallest capacity. This optimizes flexibility, batch transfer quantities, and changeover costs for total manufacturing. Other algorithms can be developed once the SC partners define the relationships and assign responsibilities.

3.5 Defining SKU 1ADOS and SAH Relationships across the SC

The processing rate of the constraint must be used to determine the amount of work to introduce at the upstream gating operation if we are to successfully lock the input at the gating process to the output of the constraint. If 8 hours of work is introduced to the constraint, 8 hours of constraint work must be introduced at the gate. However, the input items introduced at the gate may or may not be the raw materials for the items introduced at the constraint because the new work introduced at the gate must rebalance the SC from the gate to the target buffer. Therefore, we must compute the constraint hours and 1ADOS for each unit of raw material that can be introduced at the gate and establish this in the parameter table for the gating segment of the SC. BIFRS then uses these times and 1ADOSs in its algorithm to determine the input for the gate.

There are three general situations that we must consider in determining each raw material's capacity on the downstream constraint as well as each raw material's 1ADOS and SAH. The first is the simple linear case where one raw material becomes only one item on the constraint and the relationships are one-to-one. For example, if this linear

item requires one minute on the constraint, its constraint-SAH value at gating is also one minute and its 1ADOS is the same as that of the item on the constraint.

The second situation is an assembly operation and it is also a straightforward one-to-one relationship if each component goes only into one final assembly. This is shown in the following table where parts 1, 2, and n go into A. However, part 2 could also go into assembly B and B could require a different amount of time on the constraint than A. In this case we have to compute the constraint-SAH and 1ADOS for each of the different raw materials based on a weighted average of their downstream SAHs and 1ADOSs.

Assembly Operations (Many inputs to one or a few products)

Gate Items	Constraint Item and Values		Gating Items and Values			
			Item	1ADOS	SAH	
1	1ADOS = 10 Items		1	10	30	
2	A SAH = 30 Min		2	10	30	
n	Capacity = 480 Minutes		n	10	30	
	B (May be in the same or on a different SC than item A)					

The third situation is the one in which one raw material is "exploded" into more than one item on the downstream constraint. In this case the gating item values are computed as shown in the following table. In this example, we have to release 20 of input item #1 at the gate to equate to 60 minutes of work on the constraint. If all of the items on the constraint require the same constraint-SAHs, then we again have the simple one-to-one SAH relationship.

Explosion Operations (One input to many products)

Gate Items	Constraint Item and Values				Gating Item Values	
	Item	1ADOS	SAH			
	A	10	20		1ADOS = Sum A to n = 20 Items	
1	B	7	30		SAH = Sum SAHs/1ADOS = 60/20 = 3 Minutes	
	n	3	10			
	Sum:	**20**	**60**			

In each situation, we compute the SAH and 1ADOS to apply at the gating operation for each input to the gate. BIFRS then deducts the quantity of each item that will be introduced to the constraint operation from the constraint's buffer, and computes the

quantity of each raw material to introduce at the gate to rebalance the SC from the gate through the target buffer.

4. Visualizing the Specific BalancedFlow Implementation Strategy

4.1. Visualizing the Opportunities for BalancedFlow

Once the SC is fully defined, the SC partners begin to visualize the opportunities of synchronizing their strategic processes to the drumbeat of consumer demand. Each time that an item moves from the external constraint's buffer to a consumer it drops off the end of the SC and provides the earliest possible signal for each strategic process to undertake replenishment action. Each strategic process must react as quickly as changeover limitations (costs) permit. In contrast, replenishment reactions must not take place as they do on standard mass production SCs simply because items move ***within*** the SC. The red dotted lines in the following figure show the connections that must be made to carry the drumbeat of the external process to the strategic internal processes:

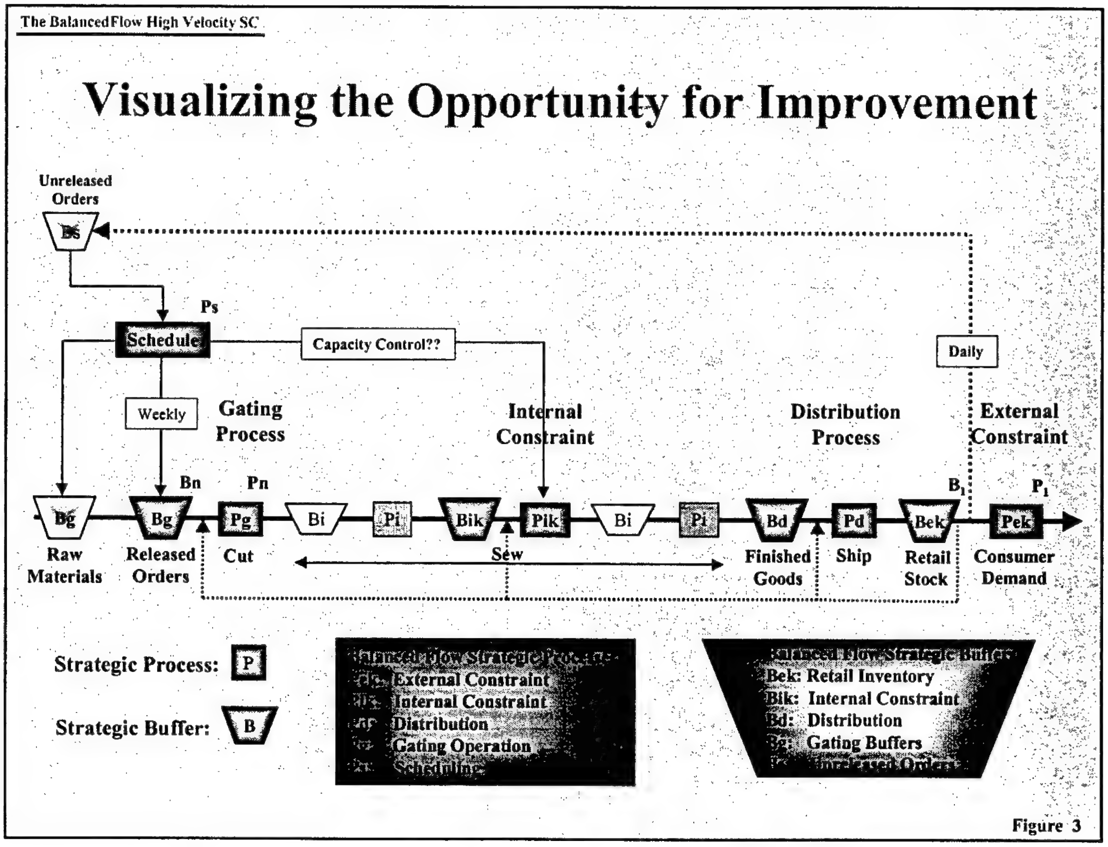

Figure 3 – Visualizing the Opportunity for Improvement

4.2. Visualizing the BIFRS Strategy

BIFRS makes the required connections as shown in the following figure. BIFRS connects the movement of product off the end of the SC to each strategic process and establishes the proper drumbeat beginning with legacy scheduling. First, it provides scheduling with

the current manufacturing requirement to re-balance the entire SC. Next, when scheduling does not occur as frequently as retail inventories are updated, BIFRS re-prioritizes the released orders to reflect the current inventory situation for each strategic segment across the entire SC. This replaces the current production line process of final scheduling for local cost optimization with final scheduling for maximum SC profitability. (Often BIFRS schedules the gating operation daily and the legacy weekly planning process is fed the results of daily scheduling to keep it current.)

Finally, BIFRS automatically accelerates (to the drumbeat of consumer demand) the movement of items in shortest supply down the SC to the external target buffer by replicating the re-balancing computations for the final two strategic processes. At the same time, BIFRS automatically applies the brakes to items in longest supply. At this point, BIFRS is balancing the SC to protect against stockouts without accelerating average item velocity or increasing inventories. High velocity should only be initiated after BIFRS is stable and sufficient balance is attained to protect the target buffer at retail.

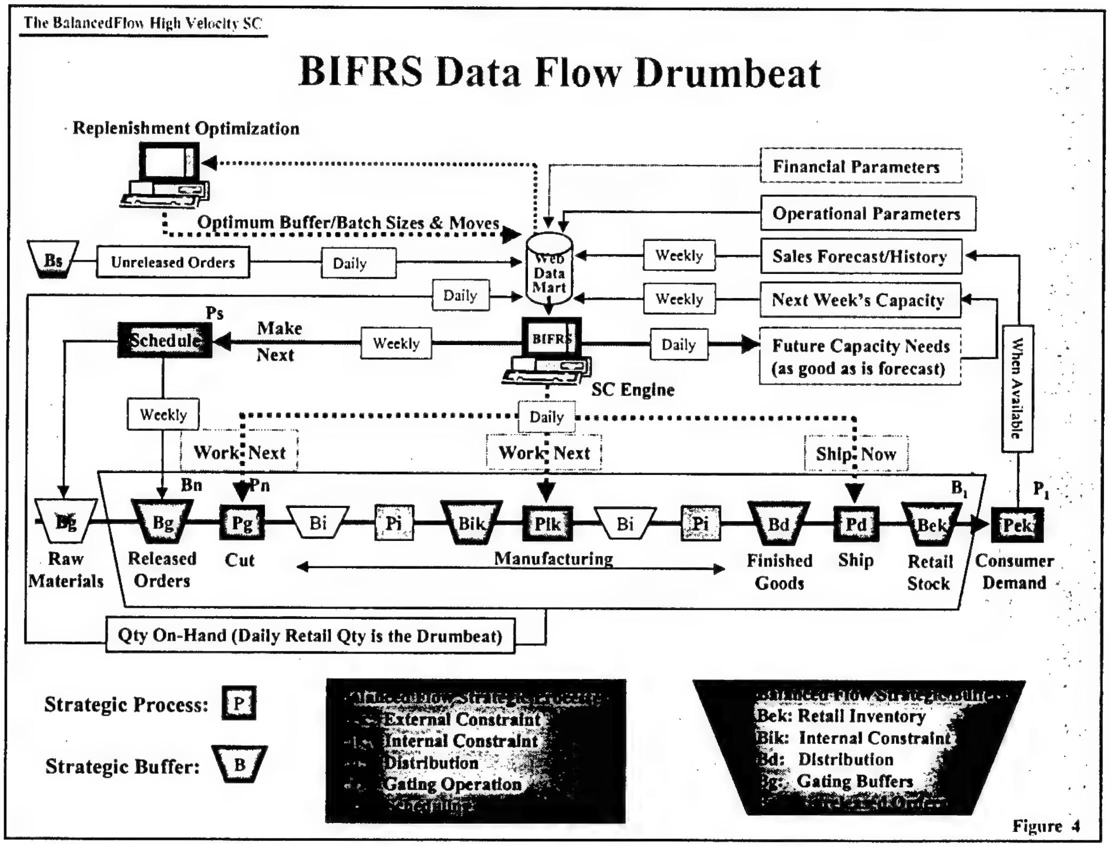

Figure 4 – BIFRS Drumbeat of Data Flow

5. Obtaining an Annual Forecast

One SC partner creates and updates the annual forecast of demand. This can be a history of demand or a forecast, but it must be for a complete year so BIFRS can address seasonal demand and compute the 1ADOS. The forecast can be in daily, weekly, or monthly periods of time, but must be at the SKU level of detail.

Forecasting errors are a major problem for conventional supply chains for many reasons. BIFRS does not correct or eliminate this problem, but minimizes its impact in the following ways:

(1) BIFRS begins with the best available annual forecast. BIFRS computes a 1ADOS for each SKU, but during later requirements calculations, BIFRS makes the final SKU mix decisions at the latest possible moment.
(2) BIFRS minimizes the current forecasting period by creating high velocity TT to shorten the forecast period.
(3) BIFRS minimizes the item-level forecasting period by reserving the capacity based on the PGC-level forecast and making the item-mix allocation decision at the last possible moment using total asset visibility.
(4) BIFRS drives the SC at least as frequently as production is initiated at the gating process so forecast errors are corrected each time production decisions are made in terms of the total quantity produced and the item mix within the total quantity.
(5) BIFRS accelerates automatically the movement of items most needed and slows those least needed by the SC at each strategic segment. It reacts instantly to changes and forecast error without waiting for human intervention.
(6) Finally, once stockouts are eliminated through BalancedFlow, real demand is captured and used to further improve forecast accuracy. When stockouts occur, sales are lost or substitutes are made masking real demand. When stockouts are eliminated, actual consumer demand is captured because items purchased and items demanded are the same.

If necessary, BIFRS converts the forecast into weekly increments, computes the seasonal inventory objective, the one annualized day of sales, and the one retail day of sales. Each time that BIFRS runs, it checks for a forecast update and re-runs these parameters if an update is detected. These are all critical driving parameters of the BalancedFlow Concept and are explained in detail in the following sections.

6. Computing One Annualized Average Day of Sales (1ADOS)

BIFRS computes one annualized average day of sales (1ADOS) by dividing the annual forecasted item demand for each SKU by 365 calendar days per year. 1ADOS is used to convert item quantities to days of supply (DOS) and DOS to item quantities. BIFRS receives SKU quantities as input, converts to DOS, calculates transfer (make and move) quantities in DOS, displays SC status in DOS, and converts back to item quantities for output of make and move recommendations. The posting of the forecast and computation of the 1ADOS is shown visually on the following figure for a PGC of 5 Items:

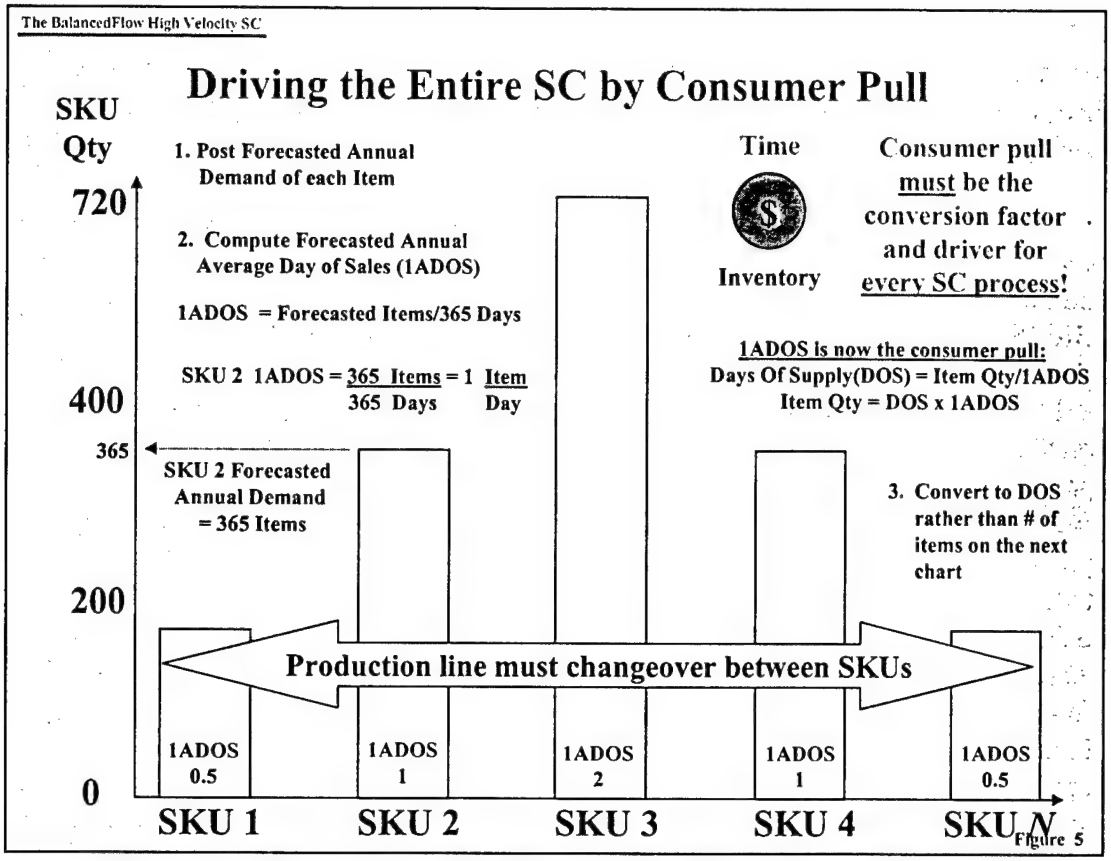

Figure 5 – Computing One Annualized Days of Supply (1ADOS)

The 1ADOS is the forecasted annual average consumption quantity per calendar day for each SKU. This is a profound change from standard supply chains. ***1ADOS is the consumer-driven pull factor, the conversion factor from time to quantity, and Lean Thinking's takt time – all in one!*** Each strategic process within a single SC must operate at the sum of all 1ADOSs for the entire enterprise to be synchronized. In this example SKU 2 has an 1ADOS of 1 item per day because the annual forecast is for 365 items. BIFRS uses the 1ADOS to convert item quantities for each SKU to DOS as shown in the following chart:

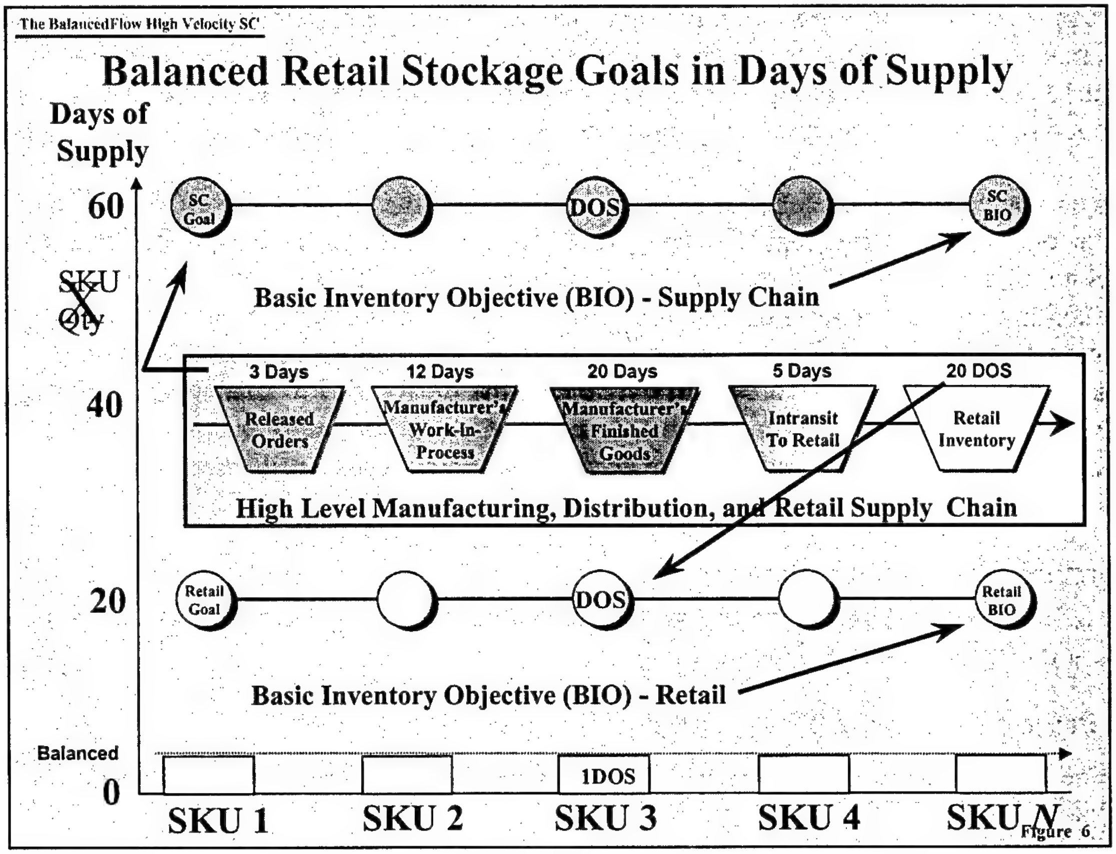

Figure 6 – Conversion of Items to Days-of-supply (DOS)

Items have been converted to DOS on this chart and 1 day of supply is the same for each SKU. This enables BIFRS to operate in the same manner that logisticians think. The quantity of a SKU is a lower level of information than is how long the quantity will support the demand. Quantity alone provides totally inadequate operational information about SC needs.

7. Connecting Demand Targets and Production Requirements

SKU 1ADOSs are the average expected demand quantity per calendar day for the entire following year and they are updated each time the forecast is updated. The sum of all SKU-level 1ADOSs is the average expected demand quantity per calendar day for the defined SC. It is also the average required production capacity per calendar day. This is the starting point for establishing the required daily production capacity for the SC and constraint process. In our example we need to produce an average of 5 SKUs per calendar day to meet the forecasted demand. This sum is our PLC 1ADOS.

The partners must next define a BIFRS cycle (how frequently BIFRS will be run) so we can convert the PLC 1ADOS to a BIFRS cycle. If our production line runs five days a week and the decision is made to run BIFRS weekly to drive legacy scheduling, our initial BIFRS cycle quantity is 35 items and BIFRS cycle time is 5 work days. We must make 7 items each workday to equal 5 items demanded each calendar day. However,

since our SKUs can have different SAHs on the constraint and entire line, we have to actually do the requirements computation based on the quantity and SAH of each SKU so we know the average hours required per BIFRS cycle rather than average item quantity required per cycle. With the production requirement in hours per BIFRS cycle, the production floor manager can easily optimize capacity and requirements.

This computed BIFRS cycle production requirement and the target buffer DOS targets are the only direct connections between BIFRS requirements and BIFRS goals. Once the DOS goals are established, the 1ADOS is used to convert to required quantities and production hours. Since the PLC 1ADOS is only a recommendation, there is no direct mathematical link between goals and requirements. The link is the amount of capacity actually used, but the results are clearly visible on the BalancedFlow management chart. ***This is the power of BIFRS; it displays the current status in a manner that facilitates immediate and fully informed capacity decision-making on the production line while doing all the right things to the RLT and Demand distribution curves!***

8. Assigning Operational Parameters

The SC partners next determine the appropriate values for the operational parameters of each segment of the defined supply chain.

8.1. Process Lead-times (PLTs) and Buffer Days of Supply (DOS)

The partners assign target DOS to each buffer and PLTs in days to each process. Again, the high velocity throughput objective is to minimize all buffers except those in strategic segments and all process lead-times (especially non-value added processes). However, the initial PLT and DOS targets should be set very high at or near existing levels so sufficient balance can be achieved without increasing inventories. Once the BIFRS software is operating satisfactorily and sufficient balance is achieved to protect the target buffer from stock outs, inventories can be lowered slowly and safely to create high-velocity throughput. Decreasing the early release times of work at the SC's gating process reduces inventory in the constraint's buffer. The previous figure shows the assigned DOS targets of 20 DOS of retail BIO and 60 DOS of SC BIO for our example SC.

8.2. Retail Basic Inventory Objective (BIO)

In our example the retail segment owner wants to begin with 20 DOS of inventory on hand for each item. This is established as the SC's BIO for the retail or external constraint's target buffer. The target buffer's BIO goal in DOS is the only value used by both the goals and manufacturing requirement's computations. The target buffer is the most critical buffer in the entire SC as it protects the external constraint of consumer demand. It must be sufficient to protect from upstream replenishment lead-times and lead-time variations plus downstream variations in replenishment demand. It must be as low as possible to minimize inventory investment costs, but large enough to contain a warning level that does not cause reaction to random demand or supply variations. A statistical analysis of historical demand and replenishment times is used to ensure the target is not set too low. It is adjusted down slowly as the SC comes into sufficient

balance to protect the external constraint from stockouts and as confidence builds in the BalancedFlow system.

8.3. Supply Chain Basic Inventory Objective (BIO)

The partners then estimate and assign current PLTs and DOS to the other SC processes and buffers. When the times are added together for each segment of our example SC, a 60 DOS BIO target is established for the entire SC. At this point our TT objective is 60 days. This means that raw materials entered into production should be converted consistently into TM every 60 days. This equates to 6 inventory turns per year. Our goal is to remove inventory from our SC to minimize TT or to maximize inventory turns.

We now have a level BIO of 20 DOS for the retail SC segment and a total SC BIO of 60 DOS. This means there should always be 60 DOS of each SKU somewhere in our SC and 20 DOS of each should always be in the retail buffer. Less than 60 DOS will give us an unacceptable risk of stock outs and more than 60 will cost us unnecessary inventory investment and interest expenses. Later, when sufficient balance is achieved to protect the external constraint, we will determine the optimal production lead time and days of supply for each SC segment and remove inventory from buffers and transfer batches to create high velocity throughput.

This establishes our initial BIFRS SC goals based on the assumption that demand variations are only random. However, most SCs exhibit seasonal and/or promotional demand variations that BIFRS accommodates through the annual forecast.

8.4. Supply Chain Seasonal Inventory Objective (SIO) Strategy

BIFRS uses the annual forecast to permit the SC partners to design and execute the best possible strategy to address the seasonal component of demand. Since the results of promotional demand are the same as seasonal demand, we use the term "seasonal demand" to also include promotional demand. Therefore, SIO includes inventory required for both seasonal demand and sales promotions as reflected in the forecast.

BIFRS breaks the annual forecast into weekly increments and first computes the SIO assuming level manufacturing capacity all year long as shown in the following figure:

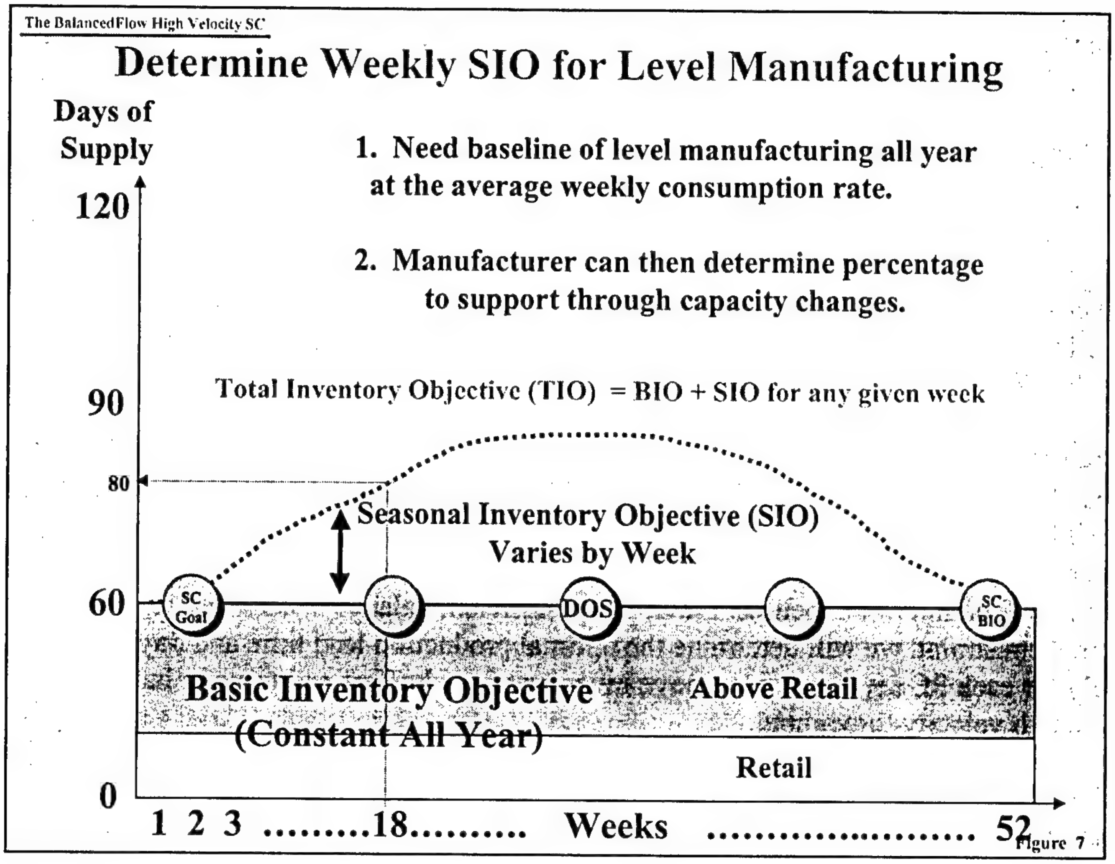

Figure 7 – Seasonal and Total Inventory Objectives (SIO and TIO)

In our example the BIO for every week is 60 DOS as discussed earlier and the SIO for week 18 is 20 DOS as shown above. The TIO for week 18 is 80 DOS and the TIO changes each week of the year based on the SIO for that week.

8.5. Meeting Seasonal Demand with Inventory and/or Capacity Changes

Seasonal demand variation is actually met in one of three ways:

(1) Capacity is held constant which requires maximum seasonal inventory to be created and depleted during the annual cycle as shown above in Figure 7.

(2) On the other extreme, capacity can be adjusted as demand changes because there is no seasonal inventory.

(3) Third, and most often, a combination of the previous two methods is employed. For example, the manufacturer could select a strategy of building 50 percent of the SIO and providing for the remainder with capacity changes.

In summary, BIFRS first uses the annual forecast to project the SIO required for constant manufacturing. Next, the SC partners determine the percentage of the SIO that will be met by modifying the manufacturing capacity. BIFRS then deducts this from the total SIO and adds the remaining SIO to the SC's BIO. This becomes the new weekly total

inventory objective (TIO) for viewing by all SC partners. The manufacturer then adjusts capacity throughout the year to meet the TIO.

8.6. Supply Chain Total Inventory Objective (TIO)

In our example, level demand could be met with level weekly production and we would always need 60 DOS of SC BIO. However, our annual forecast indicates significant seasonal demand variation. If we set our weekly manufacturing capacity at the average annual weekly demand, we will begin the year (week 1) at the end of the high demand season with only the SC's BIO on-hand. As we hold production level from week to week, we will build the SIO shown above. For example, in week 18 we will need an additional 20 DOS for a TIO of 80 DOS. This is carried to our SC DOS target line on the following SC status chart as the SC TIO. During the year the TIO targets slowly move up from and back down to the SC BIO target line as the SIO is built and consumed.

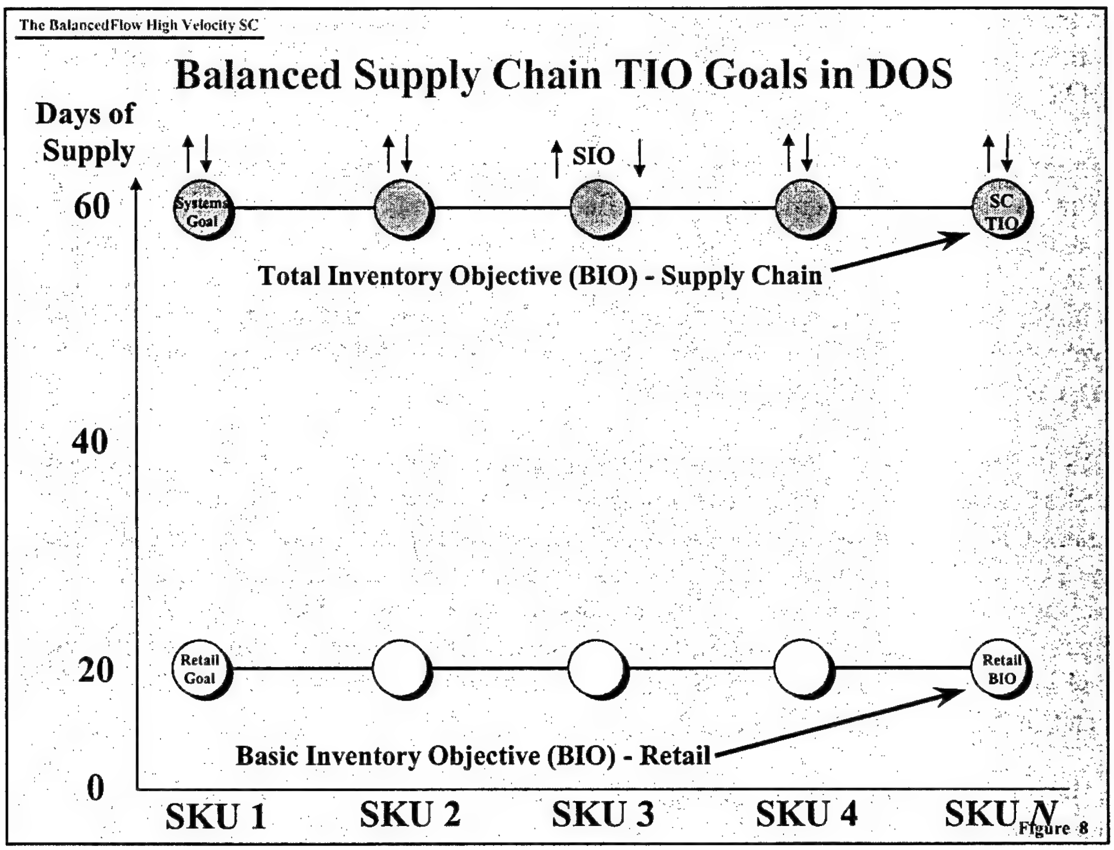

Figure 8 – Weekly TIO Management Chart

8.7. Strategy for Stocking the SIO within the Supply Chain

The initial targets are now set for manufacturing capacity and TIO for every week of the year. Next, the partners determine where the SIO is to be held within the SC. Estimating the net global impact of each location and batch transfer possibility on each of our four SC objectives best makes this decision. However, minimum cost will probably be the most important objective here because we should have optimized the other three objectives with the earlier BIO decisions. A strong alternative will be to accumulate and

ship large quantities of the SIO (with regular BIO) in bulk directly to the major customers. This will be these customers' share of the SIO and it will be transferred in large batches to minimize transfer batch handling costs.

It makes little sense to hold all of the SIO upstream and flow it out in small, costly transfer batches when it can be located downstream to further minimize the risk of stockouts while reducing operating expenses. However, a small portion of the SIO should be held upstream for added flexibility, especially to protect the customers not yet on the BalancedFlow system. In addition, the partners should decide if any of the BIO buffers should be reduced during the time the SIO is available.

8.8. Honoring the Retailer's View of 1 Retail Day-of-Supply (1RDOS)

BIFRS SC scheduling begins with the annual forecast and develops the 1ADOS so wholesale and manufacturing managers have the opportunity to plan over long time horizons and hold manufacturing requirements somewhat constant through seasonal variations in demand. BIFRS was designed to meet these long-term needs through the 1ADOS.

However, the retail SC partners must react to consumer demand over a much shorter time horizon. When seasonal demand is a significant component of total demand, they need the retail BIO to reflect the forecasted consumption rate for the time period just beyond their RLT. A day of supply for the retailer is based on the rate of consumer demand just beyond the SC's retail replenishment lead-time. This demand rate varies every week of the year the same as the SIO and matches the 1ADOS only twice each year when there is a single annual seasonal cycle of demand.

BIFRS is also designed to accommodate this near-term level of demand for the retailer. The SIO (based on the 1ADOS) ensures sufficient inventory is manufactured at the beginning of the SC to optimize all of our objectives at the same time. On the other end of the SC, BIFRS insures sufficient inventory is always on-hand to protect against stockouts at the lowest total cost. We normally do not use the 1ADOS to push inventory to the retailer. Instead, we use retail day-of-supply (1RDOS) that is computed from the annual forecast just like the 1ADOS except the computation only includes the forecasted demand through the future RLT.

The 1RDOS simply moves the appropriate part of the SIO into the retail buffers when demand is increasing and holds SIO upstream out of the retail buffer when demand is decreasing and it is not needed at retail. This achieves the important underlying objective of minimizing and equalizing the risk of stock outs at retail over the entire annual cycle with minimum retail inventories.

The retail partner decides if a variable or one local retail day of supply (1RDOS) should be used rather than the 1ADOS when replenishing retail inventories. This distinction is not important when BIFRS is first activated with high retail buffer levels, but it does become very important as inventories are reduced to optimize throughput. In practice, the DOS retail target stays fixed, but the 1RDOS changes weekly resulting in a weekly

change in the amount of replenishment shipments. The partners could also change the replenishment frequencies to change retail buffer stockage requirements.

8.9. Assigning Batch Transfer Quantity (BTQ) Parameters

Optimum batch transfer quantities (BTQs) are assigned for all processes with special attention paid to the constraint. Examples of batch transfer considerations are cutting batch sizes, constraint batch sizes, case sizes, partial case shipments, and truckload vs. less-than-truckload shipments. The frequency of running BIFRS and operational parameters also have a great impact on batch sizes. BTQs can be adjusted to optimize TT, OE, I, or capacity. Data should be gathered and calculations made to determine optimum batch sizes for each process in accordance with the TT, INV, and OE tradeoff chart in Part I.

The chart applies at any time that a decision is being made concerning BTQs. As transfer batches become smaller, the number of batches increases and batch handling expenses (OE) go up, driving profits down. This is offset directly by a decrease in work-in-process that turns immediately into cash and impacts net interest by the cost of borrowing for each year the WIP remains out of the SC. However, the comparison of these two offsetting changes just for the process being considered is only the beginning of this decision-making process.

The impact of INV and OE must be considered down the entire SC – not just for the single process. Remember that a day taken out of WIP at partial cost enables the additional reduction of a day of inventory somewhere down the supply chain – at full cost. This is a powerful TT multiplier. In addition, the shorter the supply chain, the more accurate the forecast, and the lower the buffer requirement to cover demand and replenishment variations. The cost of quality is also lower because problems are now detected downstream earlier and there is less defective inventory to repair or replace. On the OE side of the equation, there may be hidden costs of removing the inventory such as training, consulting, or the purchase of more equipment.

Finally, the positive impact on the most important objective of TT must be considered. If sales can be increased because of the faster throughput, then the increased profit potential is huge. An additional 10 percent of THROUGHPUT is easier to achieve and is a much greater profit multiplier than either a 10 percent reduction in INV or OE. In fact, for each item produced and sold beyond the established business plan, essentially all revenue is profit except totally variable costs such as raw materials, sales commissions and shipping charges!

Constraint's management plays a major role at this decision-making point if the process being evaluated is the internal constraint. If the process on which transfer batch sizes are being reduced is the internal constraint, there can be a loss of profitability rather than a gain for the SC. The direct and indirect costs of changeovers must also be considered for constraint processes.

It is important to remember that the size of every buffer and batch determines throughput across the SC. Capacity is determined by the gross efficiency of the internal constraint. These two factors are only related through the size of the buffer behind the internal constraint and the size of the process batches on the constraint. The larger the constraint's buffer and process batches, the greater the capacity of the SC, but the slower the throughput. However, non-constraint buffer and batch sizes do not affect capacity so they all must be reduced to very small transfer batches to optimize throughput.

9. Assigning Other Parameters

9.1. Conversion and Loss Factors

Conversion factors are assigned to processes that convert items from one physical form to another such as pounds of yarn to yards of fabric. Loss factors are assigned to processes that have working losses so sufficient raw materials are put into work to give the desired yield of finished goods.

9.2. Alternative Parameter Triggers

The SC partners must make decisions concerning five alternative parameter triggers:

(1) The active SKU trigger is turned on after the item's attributes are loaded so BIFRS will include the SKU in its computations. This permits the manufacturer to load all SKUs in the BIFRS Group Table at one time ahead of activation and permits additional local management actions off of the same Table.

(2) The PGC trigger is used to operate from the PGC level rather than from the SKU level for loading SKU attributes, work-loading the internal constraint and gating processes, forecasting demand, and visualizing SC status at the PGC level rather than the PLC level.

(3) The 1RDOS trigger causes BIFRS to compute retail replenishment quantities using the 1RDOS as an alternative to the 1ADOS. This trigger can be set at the PLC, PGC, or SKU levels.

(4) The alternate internal constraint trigger instructs BIFRS to use the alternate manufacturing capacity and total item SAHs rather than the internal constraint's capacity and the SAHs just for the internal constraint. This permits the loading of both sets of data in the Group Table and transitioning from the production line to the constraint in an orderly and controlled manner.

(5) The end of distribution (EOD) quantity flag instructs BIFRS to use the EOD quantity for the SKU target-buffer rather than the standard computed SKU SC goal. This permits manual override control of SKU target stockage quantities that have low or unusual demand patterns.

9.3. Replenishment Optimization Cost Parameters

Initially BalancedFlow parameters are assigned values that maintain current buffer and process times. Once sufficient balance is achieved to protect the customer from stockouts, buffer and batch inventories are reduced to maximize throughput. Buffer sizes are controlled by upstream work release dates, transfer batch sizes are computed directly, and scheduling optimizes process batch sizes. However, costs of changeovers and lost capacity limit buffer and batch reductions. Replenishment Optimization calculations are required to identify optimum batch and buffer sizes based on a number of cost parameters. Values for these cost parameters are estimated and input to compute the optimum levels of buffers, transfer batches, and BIFRS run frequencies. These cost parameters include process change over times, total changeover costs per hour, quantity per unit pack, and alternate quantities per unit pack.

10. Implementing Drum-Buffer-Rope (DBR) Constraints Scheduling

10.1. Identifying and Fixing the Internal Constraint in Place

If consumer demand is less than the capacity of the internal constrained resource, there will be excess capacity. If demand is greater than the capacity of the most constrained resource, there is a conflict and due dates can only be met with higher inventories or operating expenses. Higher operating expenses will be required initially to generate these larger inventories.

The SC's current external and internal capacity constraints (the largest process bottlenecks identified by the largest buffers) were identified in conjunction with flowing the SC buffers and processes. Consumer demand should be the external constraint that drives the entire SC to its drumbeat of demand (the **drum or 1ADOS**). ***The internal constraint should be at the SC's natural internal process that would require the most investment to take a step up in SC capacity***. The internal constraint can be any process segment of the supply chain or any external policy or necessary condition that is preventing the supply chain from attaining its goal. If the internal constraint is not at the proper location, a decision must be made to either move it or leave it where it is currently located. In either case, it must be fixed in place so that it can not move around at random because it will be used to drive all the internal SC processes. If it does move, DBR scheduling must be modified to schedule the new constraint. If the constraint moves and the new constraint has essentially the same capacity, DBR scheduling does not have to relocate its focus.

10.2. Setting External and Internal Constraint Buffer Targets

The SC partners set buffer targets for the external and internal SC constraint processes at sufficient levels to provide protection from both up-stream replenishment and down-stream demand variation. A simpler way to initially determine strategic buffer target size is to set it at a level that will last long enough to permit recovery from all possible upstream problems that could completely close the flow of product. When disaster hits, managers must both solve the immediate problem and manage the upstream portion of

the SC by the next lowest capacity process (constraint) until the constraint's strategic buffer is replenished.

The partners also determine the number of strategic processes and the number of inventory segments for the pilot SC. If the pilot does not initially include the four inventory-segment model, it should be extended before the pilot is completed and other SCs are rolled out.

10.3. Connecting the Strategic Buffers via the BIFRS Rope

BIFRS software is the **rope** that connects the target buffer in the external constraint SC segment to the buffers behind the internal constraint, the SC's first or gating process, and the distribution process (collectively called the strategic processes). The partners determine the most efficient methods of providing recurring input to BIFRS to create this rope. This completes the setup of DBR constraints scheduling for our SC.

10.4. Determining the SKU SAHs on the Internal Constraint

The manufacturing partner determines the standard allowed hours (SAHs) for each item on the constraint process. Often, SAHs are the same for SKUs of the same PGC, but they may be different.

10.5. Determining the Total Item SAHs on All Manufacturing Processes

BIFRS can also be implemented first in an alternate and less precise manner using the total SAHs required for the item on the entire production line. For example, the total SAHs for an item could be 60 minutes for the complete production line and 1 minute on the constraint. However, the SAHs for the specific constraint operation provides the optimum results and should be used eventually to drive BIFRS.

10.6. Determining the Constraint Processes' Capacity

Determine the constraint processes' capacity to match either the item's SAHs on the constraint or the entire production line discussed above. For example, we could begin by using the total SAHs for an item (60 minutes) and the total SAHs reserved on the total production line. In this case, the capacity of a small production line of 4 production workers could be 32 SAHs in a one-shift operation. Thus 32 of our items could be produced on this production line in one shift (32/1). Once we go to the specific constraint process level, the capacity must be for the specific process. For example, the specific constraint within our production line may only have 8 hours available for our item during the 8-hour shift so we could produce 8 items (8/1) rather than the 32 in the example for the total line. The capacity SAH parameter must match the item SAH parameter.

10.7. Matching New Work at the Gate to the Constraint's Capacity

The defined production line can be a straight, V, or A type line. On a straight line, each different item of raw material goes straight through the production process to the target buffer without being exploded into different items or assembled with other raw materials or parts. Here BIFRS simply releases to the gating process the quantities of the SKUs required to rebalance the entire SC constrained by the SAHs of the raw materials on the

downstream constraint. The V and A type lines are not as straightforward and the necessary computations are described earlier in Section 3.5.

10.8. Implementing BIFRS via the Throughput Time Management Chart

Implement BIFRS as shown on the following chart. This chart is both a concept demonstration chart and the primary BalancedFlow implementation and management chart:

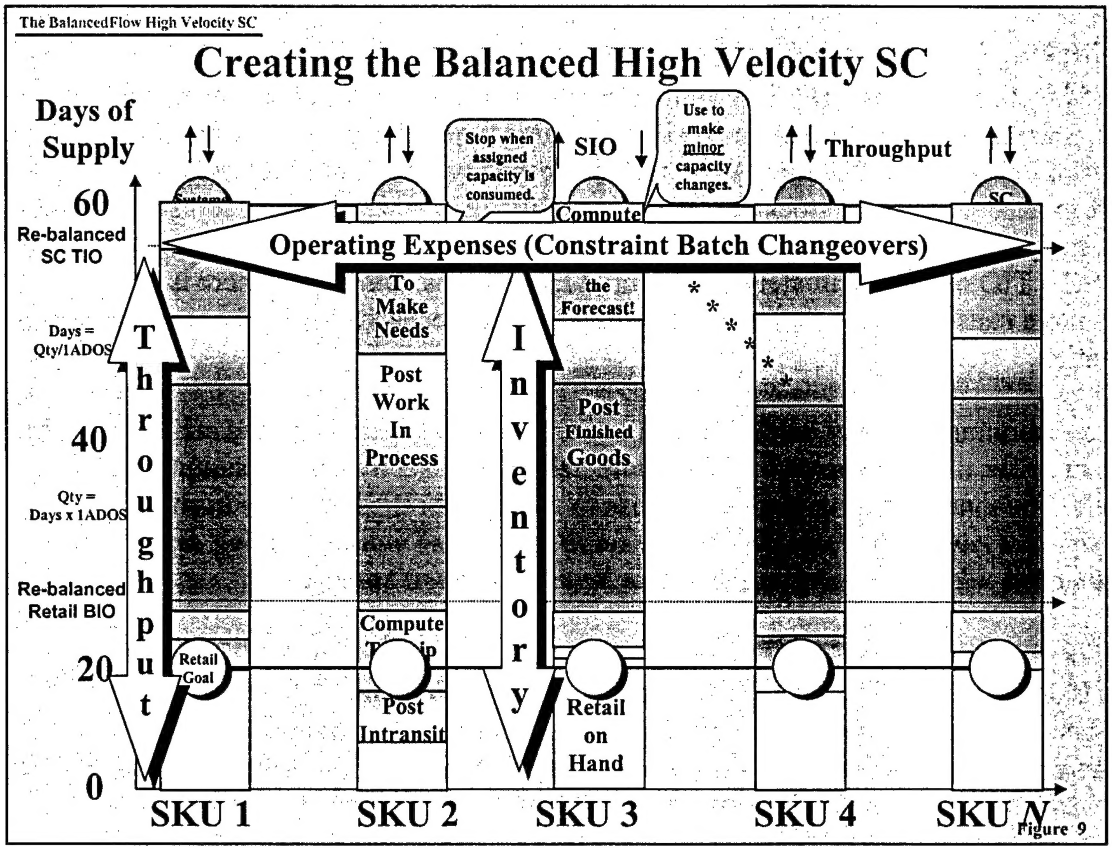

Figure 9 – Running BIFRS

BIFRS first converts retail inventories to DOS and posts them for each SKU. Next, it posts intransit inventories and finished goods. It then computes and posts shipping requirements according to the operational parameters up to the limit of available finished goods. WIP is added next. BIFRS then computes the quantities of each item (up to the agreed upon production line capacity) that should go into production immediately. Finally, BIFRS computes capacity requirements for the following four time periods to drive raw materials replenishment and near-term capacity changes. This presents the near-term future capacity needs so the SC partners can negotiate capacity and raw material changes as early as possible.

10.9. Negotiating Capacity for Future BIFRS Runs

Generally, the manufacturer makes available as much capacity as required one-week beyond current manufacturing leadtime. No changes are permitted within manufacturing leadtime unless both SC partners agree. This simply converts uncertain backorder waiting time into specified amounts of reserved capacity which is a win for all parties. BIFRS generates the item-level assortment mix just in time for scheduling. The weekly production capacity reserved/available for BIFRS is entered into BIFRS just before BIFRS is run so changes can be made up until the moment BIFRS is run – should the partners agree on a change.

11. Making Minor Capacity Adjustments on the Fly

The SC scheduler runs BIFRS to minimize retail stockouts, minimize inventories, and level manufacturing requirements – all at the same time. This directly defies the conventional wisdom that more inventory and capacity are required for optimum performance when some stockouts exist! In reality, only small capacity adjustments are necessary when the DOS in the SC establish a consistent pattern of moving away from the SC's TIO for approximately 8 sequential BIFRS runs. Otherwise, there is no assignible cause of the variation and attempts to adjust capacity will only result in greater variation.

Once a minimum level of balance is achieved, the supply chain becomes self-insuring in that surprises of high consumption of some items are offset by low consumption of others. The manufacturing engine only has to produce for those that are in shortest supply. ***It is remarkable what a relative small amount of manufacturing capacity can accomplish when it is used only to make items in shortest supply.***

12. Optimizing Buffer and Batch Sizes through Replenishment Optimization

The BalancedFlow SC is first created using existing buffer and batch sizes. Strategic buffers may even be increased to protect strategic processes from stockouts. Once sufficient SC balance is achieved to protect the external constraint from stockouts, buffer and batch sizes can be slowly reduced or optimum buffer and batch sizes can be computed. These computations use demand history and replenishment lead-times to set minimum buffer sizes. Financial parameters are used to set optimum batch sizes. Once established, these optimum buffer and batch sizes provide the fastest possible TT for optimum profitability.

13. Additional Balanced Flow Constraints Management Actions

Constraint's based improvements should be undertaken on the manufacturing line in conjunction with BIFRS scheduling to further shorten the SC and multiply profitability. Once the current and natural constraints are identified, a plan must be developed and executed to eliminate policy constraints and relocate the natural constraint if it is not in its natural location. Then, the performance of the constraint determines the performance of the entire SC and the constraint only should be scheduled with BIFRS. The output of the constraint determines the output of the entire SC. The constraint must be optimized in order to optimize the SC. On one hand we need to reduce the batch size on the constraint

to increase SC throughput, but this also reduces SC capacity because every extra changeover results in lost capacity.

If the constraint is at capacity, this brings several other TOC possibilities into the picture. First, everything possible should be done to increase the output of the constraint. This is best accomplished by chartering a world-class team to improve the gross efficiency of the internal constraint process. This includes actions such as inspecting components thoroughly while in the constraint's buffer to prevent the constraint from processing defective items, increasing the productive hours of the constraint, reducing the change over time, and speeding up the constraint. In addition, sales incentives should be reviewed to insure the sales force is using octane to maximize the sale of items that are the most profitable per unit of time through the constraint. (Most companies use standard cost accounting and have no understanding of this profit-enhancing technique.)

Optimizing the performance of the constraint is best done by a world-class teamwork effort. The very first team created should be the constraint changeover team. They should have a primary goal of cutting changeover time by at least 50%. Once this is achieved, throughput can be doubled on the constraint at no additional cost! This creates great flexibility to trade one or more of the four objectives against the others.

14. Glossary (located at page 57 of Part I)